Adaptive Management for Water Resources Project Planning

Panel on Adaptive Management for Resource Stewardship, Committee to Assess the U.S. Army Corps of Engineers Methods of Analysis and Peer Review for Water Resources Project Planning, National Research Council

ISBN: 0-309-53152-7, 138 pages, 6 x 9, (2004)

ADAPTIVE MANAGEMENT FOR WATER RESOURCES PROJECT PLANNING

Panel on Adaptive Management for Resource Stewardship

Committee to Assess the U.S. Army Corps of Engineers Methods of Analysis and Peer Review for Water Resources Project Planning

Water Science and Technology Board

Ocean Studies Board

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W., Washington, D.C. 20001

NOTICE: The project that is the subject of this report was approved by the governing board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

Support for this project was provided by the U.S. Army Corps of Engineers under contract no. DACW72-01-C-0001. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number 0-309-09191-8 (Book)
International Standard Book Number 0-309-53152-7 (PDF)

Adaptive Management for Water Resources Project Planning is available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, D.C., 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu.

Cover design by Van Nguyen, the National Academies Press. Photo of salmon courtesy of http://images.fws.gov.

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievement of engineers. Dr. Wm. A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. Wm. A. Wulf are chair and vice-chair, respectively, of the National Research Council.

www.national-academies.org

COMMITTEE TO ASSESS THE U.S. ARMY CORPS OF ENGINEERS METHODS OF ANALYSIS AND PEER REVIEW FOR WATER RESOURCES PROJECT PLANNING

PANEL ON ADAPTIVE MANAGEMENT FOR RESOURCE STEWARDSHIP*

DONALD F. BOESCH, *Chair*, University of Maryland Center for Environmental Science, Cambridge
HENRY J. BOKUNIEWICZ, State University of New York, Stony Brook
RICHARD DE NEUFVILLE, Massachusetts Institute of Technology, Cambridge
G. EDWARD DICKEY, Consultant, Baltimore, Maryland
HOLLY D. DOREMUS, University of California School of Law, Davis
CARL H. HERSHNER, JR., Virginia Institute of Marine Science, Gloucester Point
FREDERICK J. HITZHUSEN, Ohio State University, Columbus
CHARLES D. D. HOWARD, Consultant, Victoria, British Columbia, Canada
WILLIAM R. LOWRY, Washington University, St. Louis, Missouri
BARRY R. NOON, Colorado State University, Fort Collins
THAYER SCUDDER, California Institute of Technology, Pasadena
ROBERT W. STERNER, University of Minnesota, St. Paul

National Research Council Staff

JEFFREY W. JACOBS, Study Director
ELLEN A. DE GUZMAN, Research Associate
JON Q. SANDERS, Senior Project Assistant

* The Panel on Adaptive Management for Resource Stewardship was one of four panels organized under the auspices of a coordinating committee by the National Academies' Water Science and Technology Board (lead) and Ocean Studies Board to carry out studies mandated in the Water Resources Development Act of 2000.

Foreword

In the early 1800s the U.S. Congress first asked the U.S. Army Corps of Engineers (which was created in 1775) to improve navigation on our waterways. From that beginning, the Corps began a program of public works that has reshaped virtually all of the nation's river basins and coastal areas. Today we share in the benefits of those works: a reliable water transportation network, harbors that help link our economy to global markets, previously flood-prone land that is productive for urban and agricultural uses, hydroelectric power, and widely used recreational facilities.

Now, at the beginning of the twenty-first century, the Corps' program is under intense scrutiny. Traditional constituencies press the Corps to complete projects that have been planned for many years and campaign for new projects to serve traditional flood control and navigation purposes. At the same time, environmental and taxpayer groups express concerns about these projects in Congress and in the courts. Some of these groups have exposed technical errors in analyses that have been used to justify projects. For these critics, the Corps' water project development program must be reformed and the budget reduced or redirected.

Some of these same groups are pressing the administration, Congress, and the agency itself toward a new Corps mission, broadly described as environmental restoration. However, the concept of restoration awaits more precise definition, and the science of ecosystem restoration is in its infancy. Nevertheless, it is clear that restoration is a call for water resources management that accommodates and benefits from, rather than controls, annual and multiyear variability in the patterns and timing of river flows and the extremes of flood and drought.

Meanwhile, the Corps is affected by a general trend in all federal agencies toward smaller budgets and staffs. As demands for reform mount, the Corps' current staffing and organization may have to be reconfigured to provide improved and more credible planning reports.

As a result of this national debate over the Corps' programs and the quality of its planning studies, the U.S. Congress in Section 216 of the

2000 Water Resources Development Act, requested that the National Academies conduct a study of procedures for reviewing the Corps' planning studies. In addition, Congress requested a review of the "methods of analysis" used in Corps water resources planning.

In response to this request, the Water Science and Technology Board of the National Academies' National Research Council (NRC), in collaboration with the NRC's Ocean Studies Board, appointed four study panels to assess (1) peer review, (2) planning methods, (3) river basin and coastal systems planning, and (4) resource stewardship and adaptive management, along with a coordinating committee to follow these panels' progress and to write a synthesis report.

Our study panels and coordinating committee held several meetings over the course of the study period beginning in 2001. We spoke with dozens of Corps of Engineers personnel, visited several Corps projects, and heard from different groups with interests in Corps projects. We came away with an appreciation for the dedication of Corps personnel and the complications and challenges they face in trying to be responsive to local project sponsors and the nation's taxpayers.

This is not the first study of the Corps by the National Academies. However, past studies were often focused on specific projects or on particular planning aspects. The reports in this series address the agency's programs in a wider context. Because we appreciate the importance of the U.S. Congress and the sitting administration in directing Corps programs, many of our recommendations are directed to them.

The Corps has a long history of serving the nation and is one of our oldest and most recognized federal agencies, but it is today at an important crossroads. The nation, through the administration and Congress, must help the agency chart its way for the next century.

Leonard Shabman
Chair, Coordinating Committee

Preface

The U.S. Army Corps of Engineers has a rich tradition of developing and employing civil engineering methods to help meet the nation's navigation, flood protection, and other water resources-related needs. Its traditions are embodied in its motto "Essayons," a French term meaning "Let us try." However, growing concerns over unanticipated environmental consequences of Corps civil works projects, changing national policies and preferences regarding the environment, and a congressionally expanded mission in the realm of ecosystem restoration left the Corps at the end of the twentieth century seeking to address competing demands in a complex and rapidly-changing world.

In response to this new challenge, Chief of Engineers Lt. General Robert Flowers announced at the dedication of a Mississippi River diversion project in Louisiana in March 2002 a set of new environmental operating principles to guide the Corps in all of its work. These principles include, among others, to achieve environmental sustainability; to recognize the interdependence of life and the physical environment, seeking balance and synergy among human development activities and natural systems; to seek ways to assess and mitigate cumulative impacts on the environment and bring systems approaches to the full life cycle of Corps processes and work; and to build and share an integrated knowledge base that supports a greater understanding of the environment and impacts of Corps activities. These are sound principles for guidance but they pose implementation and operations challenges. Sustainability is hard to define. Interactions among human activities and natural systems are complex and synergies are elusive. Consequently, objectives are not always clear and uncertainties about outcomes are frequently great. Knowledge can and should be built upon, but understanding of natural systems is often incoherent and diffuse.

It is just such conditions that led to the development of adaptive management as a concept and approach to allow managers to take action in the face of uncertainties, to enhance scientific knowledge and thereby

reduce uncertainties, and to craft management regimes that respond to, and even take advantage of, unanticipated events. The Corps of Engineers has been incorporating adaptive management into some of its activities, particularly large-scale ecosystem restoration activities such as those in the Everglades. However, the practice is young, and options for its application in a wider range of Corps works are little explored. For example, the Corps today finds itself in the middle of several pointed planning and management controversies. In some instances reviewed in this study, the Corps has been involved in planning or "reoperations" studies that have extended over decades in an operating environment that confounds clear and decisive management actions. Adaptive management approaches offers one path forward.

Our panel assessed ways in which adaptive management might usefully be applied in Corps project planning and operations as part of a broader study conducted in response to a directive from Congress in Section 216 of the 2000 Water Resources Development Act. Section 216 directed the National Academy of Sciences to review the Corps' peer review procedures and its methods of analysis. In response, the National Research Council (NRC) appointed four study panels and a coordinating committee. Separate panel reports on review procedures within the U.S. Corps of Engineers, analytical methods, and river basin and coastal systems planning were published in addition to this report on adaptive management. The coordinating committee prepared an overarching report, based in part on the individual panel reports.

This panel held four meetings: the first and last meetings were convened at the National Research Council in Washington, D.C.; the second meeting at offices of the Corps St. Paul district office in Minnesota; and the third meeting in West Palm Beach, Florida. At these meetings we heard the perspectives and experiences related to adaptive management of individuals from Corps of Engineers Headquarters and the St. Paul and Jacksonville district offices. The St. Paul and West Palm Beach meetings included open public sessions in which representatives of other federal and state agencies participated. We also consulted with the New Orleans district office, and sought the views of Corps staff members and state and federal agency representatives on application of adaptive management in Louisiana coastal restoration.

In particular, we thank former Chief of Planning Dr. James Johnson, Lynn Martin of the Institute for Water Resources, and Harry Kitch of Corps Headquarters for their perspectives on Corps decision making and adaptive management; Lisa Hedin, Don Powell, Jeff Gulan, Leon Mucha, Dick Otto, Dan Krumholz, and Steve Tapp of the St. Paul district

office for their views regarding Upper Mississippi River ecology and management; Stuart Appelbaum of the Jacksonville District for sharing his experiences in the Everglades Restoration; Claude Strauser of the St. Louis district office for information on the Middle Mississippi River; and Troy Constance of the New Orleans district office for information regarding coastal Louisiana. Other speakers and experts who provided valuable input included Nick Aumen of the National Park Service; Gretchen Benjamin of the Wisconsin Department of Natural Resources; Mark Kraus of the National Audubon Society, Stephen Light of the Institute for Agriculture and Trade Policy; Kenneth Lubinski of the U.S. Geological Survey; John Ogden of the South Florida Water Management District, and; Jon Porthouse of the Louisiana Department of Natural Resources.

The panel owes a strong debt of gratitude to the NRC staff for its professionalism and effectiveness in ensuring that our panel adhered to its task statement, for providing discipline and experience in helping to assemble the report and effectively responding to reviewers, and for providing background research support and organizing our meetings. In particular, we thank Senior Staff Officer Jeffrey Jacobs of the Water Science and Technology Board, who worked tirelessly on numerous drafts and revisions. I, alone, count more than 100 e-mail messages from Jeff since the beginning of the drafting process requesting editorial changes and seeking additional clarity and intellectual rigor in our report. Senior Project Assistant Jon Sanders and Research Associate Ellen de Guzman ably assisted him. I also extend my deep gratitude to my fellow panel members, who participated in our discussions in this study in a professional and collegial manner, and who approached their task statement with great seriousness and intellectual curiosity. I appreciated the opportunity to work with these colleagues from several disciplines, many of whom I would never have met in my usual professional research and administration circles.

The report was reviewed in draft form by individuals chosen for diversity of perspective and technical expertise in accordance with the procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following for their review of this report: John J. Boland, Johns Hopkins University; Jeanne

N. Clarke, University of Arizona; Lt. Gen. Henry J. Hatch, consultant; Kai N. Lee, Williams College; Daniel P. Loucks, Cornell University; Robert Perciasepe, National Audubon Society, and; Timothy D. Searchinger, Environmental Defense. Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the conclusions or the recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Robert Wetzel of the University of North Carolina, and by Richard Conway (retired) of the Union Carbide Corporation. Appointed by the National Research Council, they were responsible for ensuring that an independent examination of the report was carried out in accordance with NRC institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the NRC.

Conceptually and practically, adaptive management should provide a useful path forward for the Corps as it seeks to achieve its environmental restoration as well as economic development mandate. Yet, this is not a well-trodden path—indeed there may be several paths to try. For the Corps to meet these operational and organizational challenges, it may have to extend its traditional rallying cry to "Essayons, observons, et adaptons"—let us try, observe, and adapt. Our panel gained an appreciation of the commitment of Corps of Engineers staff in meeting contemporary water resources needs, and we offer our report in the spirit of helping the agency make the transition to a new era of water resources planning and management.

Donald F. Boesch,
Chair

Contents

Executive Summary

The U.S. Army Corps of Engineers has constructed much of the nation's inland navigation, flood management, port and harbor, and coastal protection infrastructure. For much of the Corps' history, the objectives of its civil works program for water resources development have been to construct and maintain channels and ports for commercial navigation, reduce flood damages, protect beaches against erosion, and produce hydroelectric power (and more recently, to promote ecosystem restoration). There have always been criticisms of Corps analytical methods and decision making, but the agency's engineering and planning expertise was long held in high regard by many observers. But the setting of U.S. water resources management changed in the latter part of the twentieth century. There were environmental consequences of previous economic development projects, laws were passed to protect the environment and endangered species, new concepts of ecosystem science and water management were developed, and there was increased recognition of long-term risks and uncertainties within water resources management. In addition, challenges to the Corps' analytical abilities became widespread and many well-informed interest groups and citizens demanded a greater voice in project design and decision making. The U.S. Congress also gave the Corps a specific ecosystem restoration mission in the 1990s. Furthermore, biological and ecological scientists increasingly noted that hydrologic variability and extremes—which the Corps had been traditionally expected to reduce and control—are often essential to the health of aquatic and coastal ecosystems. These scientific and social changes, along with inadequacies of traditional water management frameworks and approaches, prompted the search for water management and ecosystem restoration strategies that can better respond to new knowledge and to shifting social and economic preferences.

The concept of "adaptive management" has gained attention as having the potential to help address these types of changes and challenges. Adaptive management promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management ac-

tions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a "trial and error" process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders.

The foundations of adaptive management rest in many fields, but its initial presentation as a natural resources management paradigm was in the 1970s, when it was offered as a way to help managers take action in the face of uncertainties, to reduce uncertainties, and to craft management strategies capable of responding to unanticipated events. Adaptive management is not a "one size fits all" or a "cookbook" process, as experience with the concept and its related procedures to date is limited and evolving. There are multiple views and definitions regarding adaptive management, but elements that have been identified in theory and in practice are: management objectives that are regularly revisited and accordingly revised, a model(s) of the system being managed, a range of management options, monitoring and evaluating outcomes of management actions, mechanisms for incorporating learning into future decisions, and a collaborative structure for stakeholder participation and learning. These elements have been traditionally viewed and promoted, to varying degrees, as essential to sound water resources management; adaptive management offers a framework for their integration. Implementation of adaptive management also provides the potential to respond in a timely manner to changing conditions, social objectives, and new knowledge. It can therefore help avoid costly or irreparable mistakes and unintended consequences.

The adaptive management concept is being used to varying degrees to manage water resources in several locations in the United States. For example, Congress has expressly required the use of adaptive management in the Florida Everglades ecosystem restoration program. It is a core concept of plans to restore Louisiana's coastal ecosystems. The Corps has employed various components of the adaptive management framework in select areas, including the Upper Mississippi and the Missouri River systems. Adaptive management promotes learning by experience; but learning from mistakes is difficult for both individuals and organizations, and it may be tempting to subvert adaptive management

approaches when inevitable mistakes and setbacks occur. Furthermore, even in favorable circumstances, adaptive management will not eliminate uncertainties inherent within natural resources management. Adaptive management does not represent a panacea for addressing the multiple social, economic, budgetary, and scientific challenges that attend water and natural resources management. In fact, there are instances in which adaptive management may not be appropriate, such as settings of pronounced political conflict in which participants can find no common ground. The approach, however, holds promise for helping the Corps better accommodate shifting social preferences and new scientific knowledge so that project operations can be adjusted to ensure progress toward economic and environmental goals.

In an effort to better understand the adaptive management concept and how it might be implemented to good effect within the Corps and its project operations, the Corps requested the National Research Council to convene a panel to provide advice on the subject (this report is part of a multiple panel effort, explained in this report's Foreword). The statement of task that guided this study was:

> The panel will review the Corps of Engineers' efforts in applying adaptive management concepts to project and program planning and operations, identifying adaptive management's potential and its limitations. The panel will consider the range of Corps of Engineers' responsibilities that relate to adaptive management concepts, including ecosystem restoration, flood damage reduction, and navigation enhancement. The panel will review the Corps' methods for implementing and practicing adaptive management and will identify barriers to implementing the concept. The panel will also recommend ways in which adaptive management might be usefully applied in Corps project planning and operations.

This report and the panel activity were part of a larger effort that included multiple panels and a coordinating committee. The four study panels considered different dimensions of Corps planning (peer review; analytical methods; river basins and coastal systems; and adaptive management). The coordinating committee tracked progress of the panels and wrote its own report (which includes a synthesis of the findings and recommendations of the study panels). The chairs of the four study panels were all members of the coordinating committee, which enhanced the

coordinating committee's communications with the study panels. Each panel operated independently and in accord with National Research Council guidelines. The coordinating committee also issued its own report, and in doing so, it considered draft reports from the panels (in the case of the panel on peer review, its final report was used; see NRC, 2002), as well as discussions among panels, panel chairs, and other coordinating committee members.

NEW EMPHASES IN CORPS WATER PROJECT PLANNING AND OPERATIONS

The Corps of Engineers began employing adaptive management approaches in the early 1990s. With support from its military and civilian leaders, the Corps is moving forward with adaptive management in select locales and with varying degrees of authorization and resources from the Congress. But the Corps has no mandate from the U.S. Congress to implement adaptive management principles throughout the agency and all projects that could benefit from its use. Adaptive management is a multi-disciplinary, evolving concept. Its implementation represents a challenge for a construction- and operations-oriented agency like the Corps of Engineers. Adaptive management's core principles emphasize concepts such as uncertainty, surprise, and resilience. These concepts run counter to traditional engineering planning concepts of deterministic systems, precision, and model predictions. Adaptive management stresses the value of variability and extremes in sustaining healthy ecosystems. The Corps, on the other hand, has long sought to reduce hydrologic variability by providing reliable navigation channels, reducing high flows, and stabilizing coastal areas and beaches. Adaptive management will thus entail changes in operational styles and in organizational accountability.

The Corps manages a multi-billion dollar infrastructure that controls a large portion of the nation's hydrologic systems. The agency, like several other organizations and sectors across the nation, is in the midst of a shift from an emphasis on new project construction to an emphasis on better management of existing infrastructure. The implementation of adaptive management principles would entail changes to Corps guidance, staffing, and procedures. It would also require the administration and Congress to provide resources and additional legislative guidance and clarity to the Corps. As it proceeds with implementing adaptive management, the Corps, together with the administration and the Congress,

should consider the following:

- Adaptive management practices can be relevant and useful across a variety of scales and settings. In tracking experiences with adaptive management, the Corps will benefit by a better understanding of the settings in which an adaptive approach—which may not always be appropriate—is merited and useful.
- Adaptive management may be particularly suited to large, complex ecosystem restoration projects, which entail large degrees of risk and uncertainty, multiple, and changing objectives, and phased components. Adaptive management can be especially important in multi-phase activities, as it can promote adaptation of ends and means based on lessons learned that lead to model improvements to support future decisions.
- Adaptive management entails a spectrum of approaches. These range from "passive" programs, which focus on monitoring and evaluating outcomes from a particular policy choice, to more formal and rigorous "active" adaptive management, which designs management actions to test competing models of system behavior so that models can be improved for future decision making. Ever-improving guidance could help provide advice concerning the degree to which adaptive management is applicable to various types of projects. This could range from limited monitoring programs (passive) to more formal (active) adaptive management programs with carefully-structured operational alternatives and ecosystem models.
- Although adaptive management has been linked primarily with natural resources management, it can be used to manage other types of systems. For example, sectors such as trade and transportation employ similar principles: a range of future outcomes are considered and probabilities are weighed, small-scale pilot projects are tested, actions are designed to be useful across a range of potential futures, reversible actions are favored over irreversible actions, results are monitored, and policies are modified accordingly. Adaptive management concepts could thus be useful within the Corps navigation and flood management programs, as well as to its efforts in ecological restoration.

COMPONENTS OF ADAPTIVE MANAGEMENT

Evaluations and Operations

The Corps' civil works program for water resources traditionally focused on constructing new projects. This focus has shifted because of declining federal budgets for water development, declining public support, and a decreasing number of favorable project sites. As a result, operations, maintenance, and modifications of existing infrastructure will become an increasingly important part of the Corps' work program. The creation of operations schemes that meet today's needs and preferences and that can adjust to changing conditions will require careful monitoring of project impacts, flexibility to make operational changes, closer cooperation with other agencies and with the public, and an increased emphasis on (re)allocating resources among stakeholders. Monitoring and evaluation of project outcomes are core adaptive management principles. Post-construction assessments could include the monitoring of ecological, economic, or other relevant variables, as well as broader evaluations of project or program effectiveness.

1. Post-construction evaluations should be a standard for adaptive management of Corps projects and systems.

Stakeholder Collaboration

The 1986 Water Resources Development Act (WRDA 1986) changed the financial terms of stakeholder participation in Corps projects, mandating more stringent cost-sharing requirements for local sponsors of Corps projects. WRDA 1986 has resulted in local stakeholders—most importantly, the co-sponsor—taking a greater interest in project design and implementation. Co-sponsors typically have a preferred option and are naturally interested in timely completion and in limiting expenditures. But Corps of Engineers water projects affect numerous parties beyond a local co-sponsor, and these other stakeholders may have legitimate and strong differences of opinion over project construction or operations. In addition to these types of tensions, there may be resistance among agencies, professionals, and other stakeholders to the adaptive management concept itself. Others may perceive that adaptive management poses needless and careless risks to their livelihoods. Others may perceive that adaptive management entails open-ended scientific investigations that have little relevance to management decisions.

Large, multipurpose projects affect many stakeholders that have different, often conflicting, expectations. Differences between stakeholders are inherent and inevitable in nearly all resources management settings. Adaptive management does not aim to eliminate such differences, but rather to provide an orderly approach for identifying and discussing differences. Adaptive management does not attempt to solve all problems or resolve all disputes before its implementation. If stakeholders are willing to negotiate and seek common ground on some initial steps—even small ones—adaptive management can provide a process for collaborative discussions and learning, both among stakeholders and among stakeholders and scientists. It represents the beginning of a process, not a grand master plan that must be rigidly adhered to. Adaptive management requires some degree of agreement between stakeholders, such as agreement on questions or lines of inquiry to be pursued by an adaptive approach. Adaptive management is not a substitute for willingness to collaborate and compromise, and there may be settings in which adaptive management is not possible. Properly executed, however, adaptive management can provide a process for resolving disputes, as well as social learning of environmental, economic, and other systems.

Despite challenges that attend meaningful stakeholder collaboration, it is an important part of adaptive management. Stakeholder and agency involvement should begin in the initial stages of adaptive management efforts and should include participation in periodic review of monitoring results and management models. The Corps' experiences with Shared Vision Modeling, which involves stakeholders in assessing possible outcomes through models of assumptions and key processes, is an example of one potentially useful means for promoting stakeholder collaboration.

2. Stakeholder collaboration should be an integral component in the adaptive management of Corps projects and systems.

Independent Expert Input

Results from modeling exercises, or results from economic or environmental investigations, do not always provide findings upon which all scientists and other interested parties fully agree. Such ambiguities can hinder adaptive management's iterative cycle of actions, observations, evaluations, learning, and new actions. Furthermore, as illustrated in reviews of adaptive management science programs in the Comprehensive Everglades Restoration Plan, independent expert review can point out inadequacies in modeling, monitoring, and assessment. Although such

independent advice is useful and increasingly common in some circles, the use of experts will not eliminate the uncertainties endemic to many operating environments. Adaptive management will not obviate agencies and decision makers from having to use their best judgment to make decisions in the face of uncertainties. Independent experts can, however, help validate underlying assumptions, overall logic, and planning methods and techniques, and can aid in resolving science-based disputes.

3. Independent experts should be periodically enlisted to provide advice on Corps adaptive management initiatives.

A CENTER FOR ADAPTIVE MANAGEMENT

The Corps of Engineers is a highly decentralized organization, with most of its staff members employed in 41 district offices across the nation. No mechanisms currently exist to facilitate comparison of adaptive management efforts and experiences across Corps district offices or from other organizations. Adaptive management practices should be tailored to local circumstances, but a common understanding of adaptive management principles and "best practices" across the agency would also be useful. Internal agency expertise is also important in ensuring that advice from external experts is put to best use. Agency-wide implementation of adaptive management will require a breadth of inter-disciplinary expertise that, given political realities, budgetary limitations, and differences across Corps districts, would be difficult and impractical to replicate at every Corps district office. Many Corps staff members are familiar with adaptive management principles and many of them have extensive experience in working with the concept in settings like the Florida Everglades. The more important issue is that agency-wide guidance for adaptive management (such as a "best practices" guide) is not being developed, lessons from the agency's offices across the nation are not being meaningfully and systematically shared, and staff are not specifically charged to follow developments in the professional literature or adaptive management experiences in the U.S. and around the world. Such a center would not itself implement all adaptive management programs and actions, but rather would assist Corps district offices in the design, implementation, and review of adaptively managed projects and programs. The Center would provide agency-wide guidance on adaptive management concepts, supply training, facilitation, and assistance in developing adaptive management schemes and monitoring designs, and facilitate information sharing. A center could also promote collaborative relation-

ships with other federal agencies that are pursuing adaptive management.

4. Congress should establish a Corps of Engineers Center for Adaptive Management.

ROLES OF THE ADMINISTRATION AND THE CONGRESS

The Corps of Engineers operates at the behest of the administration and the Congress. Four areas in which the implementation of adaptive management requires support of the administration and the Congress are: legislation and guidance; resources to initiate and sustain adaptive management efforts; interagency relations; and project authorization.

Legislation and Priorities

The Corps of Engineers is subject to a large body of legislation, administration guidance, and congressional committee language. As additional laws and authorizations have been passed over the years, the consistency of existing and new obligations has not been carefully evaluated. In this setting, the Corps at times appears reluctant to move away from pre-existing authorized purposes, even when it may have the legal authority to do so. This accretion of potentially inconsistent authorizations and legislation contributes to the decision making gridlock characteristic of many U.S. river systems today. Such impasses must then be broken by Congress or by the courts. A clearer sense of water policy priorities from the administration and the Congress would provide the Corps a better sense of limits and priorities within its efforts in adaptive management. Some of this gridlock also originates in conflicting aims between stakeholder groups. A line agency like the Corps of Engineers cannot legitimately resolve such conflicts, the existence of which stymies its management efforts.

5. The administration and the Congress should help resolve conflicts and inconsistencies within the body of national water policies, and should clarify water management objectives that it wishes the Corps to pursue.

Continuing Authorities

Existing authorities for most Corps projects prohibit the agency from

unilaterally implementing marked changes to project operations. Typically, the Corps constructs a project, then turns over post-construction operations and related activities to a local sponsor. Adaptive management will require a shift in this paradigm, with greater attention and resources devoted to post-construction monitoring, evaluation, and stakeholder input. The agency does, however, have some "continuing authorities" that allow for post-construction evaluations and operational adjustments. Key continuing authorities are the Section 216 authority from the 1970 Flood Control Act, the Section 1135 authority from the 1986 Water Resources Development Act, and the authorization for the Comprehensive Everglades Restoration Program. These authorizations allow the Corps to review and modify existing operations in response to significantly changed conditions, without additional congressional authorization. These authorizations were not, however, designed explicitly to promote adaptive management principles and an iterative cycle of post-construction monitoring, evaluation, and operational adjustments.

6. Congress should provide a new study authority and direction that will increase the Corps' ability to monitor and evaluate post-construction changes and periodically adjust operations of existing projects in order to increase overall project benefits (the report from the 216 studies coordinating committee provides more detailed recommendations on a new study authority for the Corps).

Resources for Adaptive Management

Successful implementation of adaptive management will require resources to support its various components, including monitoring and related science programs, support staff, and stakeholder participation.

7. Congress should allocate funding and personnel resources to help support and sustain an adaptive management program within the Corps.

Current policy guidance and budgeting procedures inhibit adaptive management practices. In the case of new Corps projects, the Corps has chosen to limit adaptive management expenditures to no more than three percent of the overall project cost and to a limited duration. In addition, most projects require a local sponsor to share in initial project costs and assume full responsibility of all post implementation costs. Adaptive management is a process that is different than traditional brick and mortar civil works construction, and it will often entail benefits that extend beyond the interests of a local project co-sponsor.

8. The administration and the Congress should consider revising cost sharing formulas to promote the application of adaptive management principles.

Interagency Relations

Effective adaptive management often requires the participation of multiple federal and state agencies. Although there are examples of useful efforts in interagency coordination (e.g., the Upper Mississippi River Environmental Management Program), improvements in this realm are necessary to move toward more comprehensive management regimes that better link environmental monitoring, social and economic changes, and policy decisions.

9. The administration should strengthen federal interagency coordination mechanisms for large-scale water resources and coastal management efforts at both the national and regional levels.

1

Report Purpose and Scope

INTRODUCTION

The U.S. Army Corps of Engineers constructed and operates much of the nation's water resources infrastructure for inland navigation enhancement, flood management, port and harbor channel maintenance, and beach and coastal protection. The agency's projects include flood control levees, large hydropower and navigation facilities on the Columbia, Mississippi, and Missouri rivers, and ecosystem restoration projects (the largest of which is currently in the Florida Everglades). Much of this infrastructure was built during the middle of the twentieth century. At the time, the need for these projects to promote economic development and human well-being by promoting navigation and commerce, by preventing damages from floods, and by providing jobs, was generally agreed upon. The Corps of Engineers was widely viewed as the consummate rational, expert-driven resources planning and management agency. Some concerns were voiced—sometimes strongly—over potential environmental impacts of some projects, but those views tended to be overshadowed by more direct economic concerns and needs. In the ensuing decades, the nation's social preferences broadened. Environmental quality became more important to many citizens (as evidenced, for example, by increases in many citizens' willingness to pay for environmental improvements, for example), and the Congress passed many pieces of environmental legislation. Moreover, it became clear that many water projects had produced unintended and not fully anticipated environmental consequences.

The Corps' traditional mission areas were broadened during the 1990s in connection with these shifting preferences. As a result of both congressional guidance and its own initiatives, the agency today is involved in ecological restoration efforts in many parts of the U.S. Meanwhile, traditional interests and users have largely remained in place. Many U.S. river and coastal systems are thus currently experiencing deep

and protracted conflicts over the goals and benefits of river management and infrastructure operations, with the Corps at the center of many of these controversies. Citizens and interest groups today tend to be better informed about the economic, environmental, and analytical aspects of federal water projects and planning studies. The Corps' professional judgment and analytical expertise is often called into question, and interest groups demand a strong voice in decision making.

In its efforts to address these tensions more effectively, the Corps is exploring additional, more efficient means for incorporating principles of "adaptive management" into its operations. Adaptive management is a strategy that aims to create flexible resource management policies that can be adjusted as project outcomes are better understood and as stakeholder preferences change. Although its roots extend into many disciplines, adaptive management's broad features are based on research conducted by ecological scientists in the early and mid-1970s. The concept gained greater currency in U.S. federal water and science agencies during the 1990s. For example, congressional legislation mandates that the Florida Everglades restoration project be managed under an adaptive management rubric, the federal science and management program for the Colorado River below Glen Canyon Dam is framed by adaptive management principles, and the Corps is promoting the concept as a guiding principle in managing the Missouri River dam and reservoir system. Adaptive management is interdisciplinary, has a strong theoretical component, and represents a departure from traditional management approaches in many ways. The adaptive management paradigm views management actions as flexible and amenable to adjustments. It emphasizes careful monitoring of economic and environmental outcomes of management actions. It also seeks to engage stakeholders in a collaborative "learning while doing" process.

This study was congressionally-mandated in Section 216 of the 2000 Water Resources Development Act (WRDA 2000). In that legislation, Congress directed the National Academy of Sciences (part of "The National Academies"[1]) to review the Corps' peer review procedures and its methods of analysis (see Appendix A, Section 216 of WRDA 2000). In response to that request, four study panels and a coordinating committee were appointed (this report's Foreword and Preface list all the study panels and further explain the 216 study structure and process). The reports from the panels and the report from the coordinating committee all stand

[1] The National Academies consists of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The National Research Council is the operating arm of The National Academies.

as independent studies, and all of which were subjected to standard National Research Council review procedures. The reports are collectively referred to as the "216" studies. This is the report from the Panel on Adaptive Management, which was charged to review and comment on the Corps' efforts at implementing the adaptive management concept, and to recommend ways in which the Corps might effectively implement adaptive management approaches (see Box 1.1). This report summarizes the Corps' experiences with the adaptive management concept, identifies challenges and limitations associated with implementing the concept, and provides recommendations on how adaptive management might be more effectively implemented within the Corps' activities and work program.

This panel held four meetings during the course of its study: a first meeting in Washington, D.C. in May 2002, during which adaptive management was discussed with staff from Corps Headquarters and from the Corps Institute for Water Resources, a second meeting in July 2002 at the Corps St. Paul, Minnesota district office, a third meeting in November 2002 in West Palm Beach, Florida (where the panel discussed adaptive management in Florida's Everglades National Park with Corps staff and other experts), and a fourth and final meeting in February 2003 in Washington, D.C. In addition to these meetings, panelists reviewed Corps of Engineers documents and spoke with other Corps officials and with several adaptive management and water resources experts.

BOX 1.1
Charge to the Panel on Adaptive Management for Resources Stewardship

The panel will review the Corps of Engineers' efforts in applying adaptive management concepts to project and program planning and operations, identifying adaptive management's potential and its limitations. The panel will consider the range of Corps of Engineers' responsibilities that relate to adaptive management concepts, including ecosystem restoration, flood damage reduction, and navigation enhancement. The panel will review the Corps' methods for implementing and practicing adaptive management and will identify barriers to implementing the concept. The panel will also recommend ways in which adaptive management might be usefully applied in Corps project planning and operations.

ADAPTIVE MANAGEMENT CONCEPTS AND RATIONALE

Conceptual Bases

Interest in the concept of adaptive management has developed in response to perceived limitations of traditional natural resources management approaches in the United States and around the world. Those limitations have included a limited ability of organizations and policies to cope with environmental changes and surprises, incomplete application of ecosystem science principles to management decisions, and a limited ability to resolve science-policy "gridlock" in large ecosystems, including river systems, in a timely fashion. Interest in adaptive management concepts may also reflect a burgeoning realization of the limits of science and engineering to redress complex public policy problems. At the beginning of the twentieth century, there was widespread optimism that scientific advances were leading toward a world of increasing certainty and precision, as well as greater social benefits through application of scientific knowledge. During the twentieth century, scientists like Bohr and Heisenberg challenged traditional paradigms with discoveries and theorems that emphasized uncertainties, complexities, and the limits of scientific knowledge (Peat, 2002). These contrasting paradigms are today reflected in distinctly different scientific schools of thought. On one hand, a Newtonian vision of the world is based on stability and predictability of natural systems. On the other, the vision promoted by Bohr and Heisenberg recognizes that change and surprises are the essence of natural systems. Newtonian principles are appropriate when working in stable systems and for designing civil engineering structures, for example, but are not fully adequate when applied to complex, dynamic ecosystems. The late Kenneth Boulding provided an eloquent statement on these contrasting paradigms:

> Prediction of the future is possible only in systems that have stable parameters like celestial mechanics. The only reason why prediction is so successful in celestial mechanics is that the evolution of the solar system has ground to a halt in what is essentially a dynamic equilibrium with stable parameters. Evolutionary systems, however, by their very nature have unstable parameters. They are disequilibrium systems and in such systems our power of prediction, though not zero, is very limited because of the unpredictability of the parameters themselves. If, of course, it were possible to predict the

> change in the parameters, then there would be other parameters which were unchanged, but the search for ultimately stable parameter in evolutionary systems is futile, for they probably do not exist (Boulding, 1981).

Adaptive Management Applications

Changes and surprises cause managers in many fields to adjust strategies as new information accumulates and as new practices are developed. The reality of changing conditions is especially relevant to public works projects with life spans measured in decades, and to agencies like the Corps of Engineers that construct and operate those projects. Unintended consequences have often attended the operations of Corps projects because of incomplete knowledge of ecological and economic conditions and trends. As the world changes, or as unanticipated consequences are revealed, organizations should adjust plans and operations to deal with the new conditions and to incorporate improved understanding. Adaptive management is a commonsense strategy for addressing the reality of a changing and uncertain environment.

Recognition of the need to adjust management strategies can derive from at least three broad sources. First, *scientific advances* can provide better understanding of the complex linkages between human activities and environmental impacts. The Corps has experienced such paradigm shifts, one of the most famous being the abandonment of its "levees only" strategy in the early twentieth century (Barry, 1997). Through much of the nineteenth century and the early twentieth century, the Corps of Engineers based its flood control program on the notion that levees were, by themselves, adequate for controlling all floods, and that other measures (e.g., upstream reservoirs) were not necessary. Devastating floods along the lower Mississippi River in 1927 proved the inadequacy of this policy and ultimately resulted in the Corps moving toward a broader approach to manage flood risks (ibid.). Second, *environmental changes and variability* affect the operations and impacts of Corps projects. For example, climatic variability may affect precipitation patterns, which in turn may affect the parameters of dam and reservoir operations (Rhodes et al., 1984). Human-induced changes may also affect local and regional environments in ways that change project performance or management goals. Thirdly, *shifts in social objectives and preferences* may challenge conventional operations schemes. In the United States, for

example, the 1960s and 1970s marked a period of increasing concern over environmental issues. The Corps is addressing these types of change in many river systems across the U.S. (Table 1.1 lists examples where new objectives may conflict with or limit full achievement of original objectives).

Within the Corps civil works program, adaptive management applications have been mainly limited to environmental or ecosystem restoration projects. In the context of Corps water resources projects, ecological restoration generally entails re-establishing some degree of natural hydrologic and related physical, chemical, and biological processes. It may also entail re-establishing some level of biotic resources, with the notion that the ecosystem being restored will eventually sustain itself structurally and functionally. Because navigation and flood control projects also entail complex interactions and uncertain outcomes,

TABLE 1.1 Original and Subsequent U.S. Water Project and System Management Objectives

Original objective(s)	Additional/new objective(s)
Upper Mississippi River: navigation	ecological and recreational benefits
Middle Mississippi River: navigation, flood control	ecological and recreational benefits
Lower Mississippi: navigation, flood control	wetland restoration/preservation
Columbia River: hydroelectric power, navigation, flood control	salmon habitat and population restoration
Missouri River: navigation, flood control, irrigation	ecological and recreational benefits
Everglades: arable land, irrigation, flood control	Everglades restoration, water supply
Coastal Louisiana: flood protection, navigation, oil and gas development	wetland restoration
Glen Canyon Dam: hydroelectric power	recreation; endangered species protection
Kissimmee River: flood control	wetlands restoration

adaptive management approaches hold promise for managing the full array of Corps of Engineers projects. Moreover, as the types of social benefits expected from Corps projects have broadened over time, an approach that periodically (re)evaluates project outputs and subsequently adjusts operations policies is essential to ensure that project outputs and social demands remain synchronized over time.

REPORT ORGANIZATION

Chapter 2 builds upon discussions in this introductory chapter and further explores adaptive management theories and practices. It notes the many disciplines from which contemporary adaptive management concepts are derived, and lists the key components of adaptive management programs. Chapter 3 describes internal and external factors that affect the use of adaptive management approaches within the Corps of Engineers. Examples of internal factors include organizational structure and disciplinary expertise of Corps staff, while external factors include congressional legislation and the Corps' relationships with other federal and state agencies. Chapter 4 presents case studies of efforts to implement adaptive management in large river and aquatic ecosystems. All these case studies focus on Corps efforts, but a case study of the Colorado River in Grand Canyon is also included for comparative purposes. Chapter 5 offers several recommendations for ways in which the Corps might successfully apply adaptive management. Chapter 6 presents a brief epilogue.

2

Adaptive Management Theories, Frameworks, and Practices

INTRODUCTION

Formal development of adaptive management as an approach for natural resources management can be traced back to the 1970s and to research conducted at the International Institute for Systems Analysis (IIASA) in Laxenburg, Austria (see Holling, 1978). As mentioned in the previous chapter, adaptive management draws from concepts within many different disciplines. Part of adaptive management's philosophical foundations, for example, lie within the field of industrial operations theory (Johnson, 1999; see also Everett and Ebert, 1986). Although Holling's seminal 1978 volume emphasizes ecosystem dynamics, it includes references to macroeconomics (Hafele and Burk, 1976), decision theory (Keeney, 1977), organizational behavior (Cyert and March, 1963), and policy analysis (Brewer, 1975). Thus, even in its articulation by ecological scientists in the late 1970s, adaptive management possessed strong interdisciplinary roots. Adaptive management seeks insights into the behavior of ecosystems that are utilized by humans, and it draws upon theories from ecosystem sciences, economics and social sciences, engineering, and other disciplines. Adaptive management incorporates and integrates concepts such as social learning, operations research, economic values, and political differences with ecosystem monitoring, models, and science. Applications of adaptive management principles within the Corps of Engineers to date have focused on aquatic and hydrologic systems. Although this report encourages the Corps to consider ways in which adaptive management principles could be applied in other parts of its work program, as applications within the agency to date have focused on ecosystem restoration, these experiences are emphasized within this report.

Adaptive management does not postpone actions until "enough" is known about a managed ecosystem (Lee, 1999), but rather is designed to support action in the face of the limitations of scientific knowledge and the complexities and stochastic behavior of large ecosystems (Holling,

1978). Adaptive management aims to enhance scientific knowledge and thereby reduce uncertainties. Such uncertainties may stem from natural variability and stochastic behavior of ecosystems and the interpretation of incomplete data (Parma et al., 1998; Regan et al., 2002), as well as social and economic changes and events (e.g., demographic shifts, changes in prices and consumer demands) that affect natural resources systems. Adaptive management aims to create policies that can help organizations, managers, and other stakeholders respond to, and even take advantage of, unanticipated events (Holling, 1978; Walters, 1986). Instead of seeking precise predictions of future conditions, adaptive management recognizes the uncertainties associated with forecasting future outcomes, and calls for consideration of a range of possible future outcomes (Walters, 1986). Management policies are designed to be flexible and are subject to adjustment in an iterative, social learning process (Lee, 1999).

Adaptive management is intended to increase the ability to fashion timely responses in the face of new information and in a setting of varied stakeholder objectives and preferences. It encourages stakeholders to bound disputes and discuss them in an orderly fashion while environmental uncertainties are being investigated and better understood. Management decisions are often difficult to change because managers are subject to ordinary human failings, including a tendency to resist recognizing and learning from their own errors. In a bureaucracy, this tendency may be amplified. Adaptive management can help reduce decision-making gridlock by making it clear that decisions are provisional, that there is often no "right" or "wrong" management decision, and that modifications are expected. Adaptive management should help stakeholders, managers, and elected officials and other decision makers recognize the limits of knowledge and the need to act on imperfect information.

Some of the disappointments with past efforts in implementing adaptive management can be traced to confusion surrounding definitions. There are many dimensions of adaptive management, and the ambiguities inherent in adaptive management can result in policymakers, managers, and stakeholders developing unique definitions and expectations. The term is complex and multidisciplinary, and participants in adaptive management programs should strive to become familiar with the broad literature on the topic. It should also be recognized that adaptive management is an evolving theory and practice and that experiences to date are limited (Lee, 1999). The richness and potential of the concept, however, have drawn a great deal of attention, and its prospects for redress-

ing complex public policy problems have generated a great deal of interest. Complex natural resources management problems, including many of those in which the Corps of Engineers is involved, defy simple solutions, and some of the case studies examined in this report may require an approach like adaptive management to reach agreeable, long-term solutions.

A SPECTRUM OF ADAPTIVE MANAGEMENT PRACTICES

Scientific inquiry can be approached and knowledge can be gained in many different ways. If these various means of inquiry are placed along a spectrum, formal, laboratory experimentation lies near one of this spectrum, and unmonitored, unstructured learning lies near the other end (Table 2.1). Table 2.1 lists examples of different modes of learning, and shows that learning by adaptive management lies somewhere between

TABLE 2.1 Examples of Learning Modes

Each mode of learning	makes observations...	and combines them...	to inform activities...	...that accumulate into usable knowledge
Laboratory Expeirmentation	Controlled observation to infer cause	replicated to assure reliable knowledge	enabling prediction, design, control	theory (it works, but range of applicability may be narrow)
Adaptive Management (quasi-experiments in the field)	systematic monitoring to detect surprise	integrated assessment to build system knowledge	informing model-building to structure debate	strong inference (but learning may not produce timely prediction or control)
Trial and Error	problem-oriented observation	extended to analogous instances	to solve or mitigate particular problems	empirical knowledge (it works but may be inconsistent and surprising)
Unmonitored Experience	casual observation	applied anecdotally	to identify plausible solutions to intractable problems	models of reality (test is political, not practical, feasibility)

SOURCE: Modified from Lee (1999).

formal laboratory science and a "trial and error" mode of learning. Adaptive management is not simply a "trial and error" process, but rather represents a more systematic "learning while doing" process (Lee, 1999). Some degree of learning is inevitable in almost any management approach; adaptive management is structured to make that learning more systematic and efficient, although this is questioned by some (Gunderson, 1999; see McLain and Lee, 1996).

A distinction is often made between adaptive management approaches that are "passive" and those that are "active." Within "passive" adaptive management, a single, preferred course of action, based on existing information and understanding, is selected. Outcomes of management actions are monitored, and subsequent decisions are adjusted based on the outcomes. This approach contributes to learning and to more effective management, but it is limited in its ability to enhance scientific and management capabilities for conditions that go beyond the course of action selected. By contrast, an "active" adaptive management approach reviews information before management actions are taken. A range of competing, alternative system models of ecosystem and related responses (e.g. demographic changes; recreational uses), rather than a single model, is then developed. Management options are then chosen based upon evaluations of these alternative models (Table 2.2 provides greater detail on "passive" and "active" adaptive management approaches). All modes of adaptive management require outcomes of management actions to be monitored. Learning is achieved by observing system responses to management actions. A lack of concordance between observation and expectation should lead to a revised model(s) of how the system functions and, ideally, to revised future management options and actions.

ELEMENTS OF ADAPTIVE MANAGEMENT

The theories and concepts of adaptive management themselves represent a work in progress. As mentioned, there is no accepted, clearly-defined course of adaptive management, and there may be instances in which adaptive strategies or a formal program may be inappropriate (e.g., protracted political disputes; see Lee, 1999). There is no prototype for its implementation, and no "cookbook"-type set of steps or building blocks that will immediately constitute an adaptive management program. It is context-specific, it involves feedback and learning between

TABLE 2.2 Passive and Active Adaptive Management

	PASSIVE Adaptive Management	ACTIVE Adaptive Management
Characteristics Related tot eh Nature of The Ecological Problem		
Ongoing monitoring	Essential	Essential
Decision points	Multiple	Multiple
Choice at decisions points	Best apparent management choice is selected at each decision point.	A range of management choices is explored through modeling. Inferences are made and the best apparent alternative chosen and applied later.
Characteristics Related to Internal Organization Chart		
Analytic requirements	Moderate to high; reliability depends on quality of monitoring and time-series analysis.	High, including experimental design and statistical analysis at end of experiment when inferences are made.
Social organization required of the decision makers	Continuity of oversight; timeframe may exceed manager's professional tenure.	Organizations should nurture curiosity, credit and checking. Timeframe may exceed manager's professional tenure.
Characteristics Related to External Social Context		
Goals and objectives	Goals and objectives should be clearly defined.	Goals will include a balance between management goals and learning. Hypotheses to be tested must relate to those goals.
Uncertainty and learning	Learning is a goal, but information at later decision points may be unreliable, owing to possible confounding factors.	Learning is a goal, and good experimental design should produce reliable new information for later decisions.

SOURCE: Adapted from Anderson et al. (2003).

scientists, managers, and stakeholders, and it is likely to entail a mix of progress and setbacks. But there is a rich literature on the topic, informed by ecological and social scientists alike, and there have been some efforts toward its implementation in the U.S. and abroad. Elements of adaptive management that have been identified in theories and practice are:

1. Management objectives that are regularly revisited and accordingly revised. Political differences among stakeholders, or competing paradigms among cooperating scientists, are inherent and unavoidable. Recognition and discussion of such differences should be part of adaptive management and its learning processes. But adaptive management participants must have some level of agreement if adaptive management is to be useful; a setting in which there is no agreement on goals, or modes of progress, is likely to render potential adaptive management applications ineffective. As Lee (1999) explained, "Unbounded conflict can tear apart the social fabric, thwarting learning." Participants in adaptive management programs must at least agree upon key research questions or lines of inquiry to be pursued by an adaptive approach (ibid.). Some agreement on larger objectives could help better define program direction; but if full agreement on ecosystem management goals existed (an unusual condition), there would be a reduced need for adaptive approaches. Adaptive management is a means for bounding and addressing disputes and differences. As adaptive management proceeds, not only will ecosystem understanding by participants increase, but social and political preferences are likely to evolve, and environmental and social surprises may occur. Key questions, paths of inquiry, and programmatic objectives should be regularly reviewed in an iterative process to help participants maintain a focus on objectives and appropriate revisions to them.

2. A model(s) of the system being managed. An explicit baseline understanding of and assumptions about the system being managed will help provide a foundation for learning (Holling, 1978; Lee, 1999; Walters, 1986). A system model(s) helps explain responses to management actions and helps identify gaps in and the limits of scientific and other knowledge (Box 2.1 discusses model construction and applications). Model sophistication and complexity should be tailored to the decision at hand. Active adaptive management employs multiple, quantitative models to generate hypotheses about the system (Walters, 1986; Walters and Holling, 1990). These models contain clearly-defined variables that characterize the state of the system and its rates and directions of change.

BOX 2.1
Models And Adaptive Management

The adaptive management literature refers frequently to "models" for use in scientific investigations and as aids in decision making. A model represents and simplifies reality by showing relationships between the objects of a theory, causal interactions, and the states of a system (Pickett et al., 1994). Models are useful abstractions of the dynamics of more-or-less complex systems and may be verbal, physical, graphical, or quantitative. Scientists and engineers often construct models to test hypotheses of how a process or a system functions, as there are limits to testing hypotheses on actual objects or structures. For example, the Corps of Engineers has long used physical models to test assumptions regarding river hydraulics, sediment transport, and environmental impacts of barge passage. Models are, however, are simplifications of reality and can rarely perfectly simulate real world conditions.

The ecosystem models referred to in this report are mainly numerical models, in which elements and processes of a given ecosystem (e.g., river corridor, or a stand of trees) are quantitatively expressed in algorithms contained within a computer program. They offer scientists the opportunity to evaluate multiple ideas and hypotheses about disturbances, diseases, and other impacts on a given species or multiple species, but are not a substitute for empirical tests of hypotheses. Numerical models provide an opportunity to see how ecosystems might respond to a variety of human actions, and the better the model is able to simulate reality, the greater its credibility. Numerical models of ecosystems are useful for adaptive management applications and programs, as they allow scientists and stakeholders to observe how impacts vary across multiple management actions. The value of numerical models should be tempered with a clear understanding of model limitations and uncertainties in model projections, as the lack of communication or lack of common understanding between model builders and users may result in confusion and misinterpretation of model results.

Mathematical models of the managed system are often developed to help understand systems behavior. But in poorly understood systems, or when the scale or risks of the actions being considered do not justify the expense of rigorous models, simple schematic diagrams can serve as useful conceptual models. Adaptive management recognizes the need for action in the face of uncertainty, and complete or perfect ecosystem models (which are not likely to be perfected in any case) do not need to be crafted in order to support decisions (Walters, 1997). Simple models

can educate decision makers and participants by organizing information, highlighting missing information that might be acquired by monitoring, providing a framework for comparing alternatives, and forcing managers to consider their understanding and assumptions of the system (Salafsky et al., 2001). The focus should be on learning, not on getting ready to learn (Lee, 1999). No matter what the setting or types of models used, it is important that adaptive management participants understand model assumptions and limits so that model results are not equated with reality.

3. A range of management choices. Even when an objective is agreed upon, uncertainties about the ability of possible management actions to achieve that objective are common. That is, existing data rarely point to a single "best" management policy. For each decision, the range of possible management choices is considered at the outset in light of stated objectives and the model(s) of system dynamics. This evaluation takes into account the likelihood of achieving management objectives and the extent to which each alternative will generate new information or foreclose future choices. When possible, simultaneously implementing two or more carefully monitored actions can allow for rapid discrimination among competing models. Within the field of water resources planning and management, Gilbert White for decades strongly encouraged water managers and organizations to consider a broad range of alternatives for addressing water resources problems and opportunities (White, 1961).

4. Monitoring and evaluation of outcomes. Adaptive management requires some mechanism for comparing outcomes of management decisions. The gathering and evaluation of data allow for the testing of alternative hypotheses, and are central to improving knowledge of ecological, economic, and other systems. Monitoring should focus on significant and detectable indicators of progress toward management objectives. Monitoring should also help distinguish between natural perturbations and perturbations caused by management actions. Monitoring, in and of itself, however, does not ensure progress, and monitoring should not be equated with adaptive management. Monitoring programs and results should be designed to improve understanding of environmental and economic systems and models, to evaluate the outcomes of management decisions, and to provide a basis for better decision making (ideally, independent estimates of the value of monitoring information and programs will be periodically conducted). Monitoring systems should be an integral part of program design at the outset and not simply added *post hoc* after implementation (Holling, 1978).

5. A mechanism(s) for incorporating learning into future decisions.

Adaptive management aims to achieve better management decisions through an active learning process. Objectives, models, consideration of alternatives, and formal evaluation of outcomes all facilitate learning. But there should be one or more mechanisms for feeding information gained back into the management process. The political will to act upon that information must also exist. Without a mechanism to integrate knowledge gained in monitoring into management actions, and without a parallel commitment and the political will to act upon knowledge gained from monitoring—which will not eliminate all uncertainties—monitoring and learning will not result in better management decisions and policies. In addition, adaptive management organizations must likewise have some degree of flexibility in order to adjust operations in light of new information, environmental changes, and shifting social and economic conditions and preferences (Gunderson, 1999).

6. A collaborative structure for stakeholder participation and learning. The inclusion of parties affected by ecosystem management actions in decision making is becoming a broadly-accepted management tenet of natural resources management programs in the U.S. and around the world (WCD, 2000). The Corps of Engineers, for example, has long supported this notion, and stakeholder outreach is a part of Corps planning studies in many locales. Achieving meaningful stakeholder involvement that includes give and take, active learning (through cooperation with scientists), and some level of agreement among participants, represents a challenge, but is essential to adaptive management. This implies that some of the onus for adaptive management goes beyond managers, decisions makers, and scientists, and rests upon interest groups and even the general public. As mentioned, even though differences between stakeholders are inevitable, some agreement upon key questions and areas of research is essential to adaptive management of public projects (Lee, 1999). Stakeholders may also need to exhibit flexibility and some willingness to compromise in order for adaptive management to be implemented effectively. As one expert in the field has noted, "In a nutshell, if there is no resilience in the ecological system, *or flexibility among stakeholders in the coupled social system*, then one simply cannot manage adaptively" (Gunderson, 1999, emphasis added).

ADAPTIVE MANAGEMENT OF OTHER ENTERPRISES

The concept of adaptive management is not restricted to natural resources or ecosystem management, as similar concepts have been applied

in fields such as business, education (Dewey, 1938), engineering (de Neufville, 2000; de Neufville and Odoni, 2003), geography (White, 1988), and public administration (Lindblom, 1979). Related concepts and practices from these other disciplines include "learning by experience," "ex post audits," and "muddling through," and designers of engineering systems may refer to "flexible planning" rather than "adaptive management." Alternative forms of this concept have been and are being applied in the broade area of strategic planning, which often emphasizes adaptability in system development and management. The traditional approach to developing infrastructure systems often centers on a "master plan," or a linear path to a selected, well-defined endpoint (NRC, 2003a). In practice, developers first engage in a planning exercise in which they lay out a desired end state for the system (the master plan, i.e., objectives). Within the context of rigidity that characterizes some traditional design practices, the view that designers should design and manage systems flexibly presents a challenge. But several concepts of flexible planning and engineering systems management have been developed that frame the planning process as a series of choices with indeterminate consequences (de Neufville, 2004).

Flexible Management of Engineering Systems

Practices for the planning, design, and management of large, complex engineering systems are evolving in fundamental ways. Professional practice is in the middle of a transition that is reshaping design, evaluation, and implementation of major civil engineering developments. Individually, experts do not share a consensus on exactly how to describe this evolution. Collectively, however, traditional norms of practice are often viewed as insufficient in current settings and given current knowledge (de Neufville and Odoni, 2003). Current and prospective Corps of Engineers practice should be sensitive to these changes. In broad terms, the evolution is from simplicity to complexity. Most major civil investments were traditionally designed and implemented primarily in terms of single investments, for single purposes, on the basis of a single forecast of future events, and with a narrow focus on construction (Table 2.3 summarizes practices that were fairly standard as of a generation ago, as well as ways in which those practices are evolving).

TABLE 2.3 Trends in the Evolution of Civil Engineering Design Practice

	Nature of Change	
Design Element	From Traditional	Broadening To
Scope	Project	System of projects
Purpose	Single purpose	Multiple and sometimes conflicting objectives
Means	Structural	Nonstructural
Focus	Construction	Long-term Management
Risk Recognition	Little	Extensive

Engineering design practices are today more sophisticated than in a previous era. Although its evolving nature precludes a precise definition, its main contours can generally be described. Most fundamentally, it is generally accepted that the interactions between projects are important, and that designs should consider any single project as part of a larger whole. These approaches are standard elements of today's engineering design textbooks (e.g., de Neufville, 1990). An important aspect of evolving concepts of engineering practice is the way uncertainty is recognized and addressed. It is today widely appreciated that many consequences of civil engineering investments cannot be precisely forecasted. The example of the Florida Everglades (discussed in Chapter 4) is illustrative, as this project is set within a context of demographic and ecological changes that are rapidly changing southern Florida. In this region, the nation is attempting something never done before, in the midst of substantial scientific uncertainties about the effectiveness of solutions that have been proposed. At the very least, it must be recognized that even the best projections of future system performance will contain some uncertainties.

Recognizing that the consequences of designs entail risks leads to an important feature of current best practice in the design of engineering systems. Promoters and developers of engineering and other projects are responsible for managing inevitable uncertainties associated with those projects. On the one hand, there is a need to take advantage of new opportunities for improving water resources systems performance through advances in engineering, biophysical sciences, and social sciences. On the other hand, proposed solutions should seek to minimize the potential for negative consequences and seek to keep development options open by, to the extent possible, proceeding incrementally and evaluating the results of design and planning decisions. Whether the objective is to take advantage of new opportunities or to insure against bad outcomes, the goal is to create the capacity to respond appropriately as new situations—which may include unforeseen surprises—develop. Flexibility

over the life of the project is essential to effective development and functioning of civil engineering systems.

Adaptive Implementation, Staging, and Site Management

Adaptive management approaches are increasingly being seen as useful in dealing with problems where the outcomes, and even goals, are uncertain. Recent reports of National Research Council committees have recommended the use of adaptive strategies and methods in addressing Total Maximum Daily Load (TMDL) approaches to water quality management (NRC, 2001a), in the staged development of geological repositories for high-level radioactive waste (NRC, 2003b), and in clean-up of hazardous waste sites at U.S. Navy facilities (NRC, 2003c).

Under the Clean Water Act, the Environmental Protection Agency (EPA) is obligated to implement the TMDL program when ambient water quality standards are not attained through the National Pollutant Discharge Elimination System (NPDES) permit program. The maximum discharge loads that can be tolerated, consistent with attaining water quality standards, must be determined and allocated among sources. There are uncertainties throughout this process, which over time could result in changed requirements and even goals. *Adaptive implementation* of TMDL plans has therefore been recommended, which involves a cyclical process in which TMDL plans are periodically assessed for their achievement of water quality standards including designated uses (NRC, 2001a). If designated uses and goals are not being achieved after implementation, scientific data and information should be used to revise the plan, thus ensuring that the TMDL program is not halted but progresses while better information is collected and analyzed with the intent of improving on initial TMDL plans.

Adaptive staging (as opposed to linear staging with a predetermined path to a well-defined endpoint) was recommended as a promising approach to the development of geological repositories for high-level radioactive wastes, such the Yucca Mountain Project (NRC, 2003b). Adaptive staging is a way to deal with uncertainties regarding not only environmental factors, but also programmatic, safety, security, institutional, regulatory, and societal variables throughout the construction, operation, closure and post-closure phases of repository development. Adaptive staging provides a flexible reference framework so that the ultimate path to success, and the endpoints themselves, are determined by knowledge and experience gathered along the way. Adaptive staging is a

deliberate, incremental decision-making and management process, fully consistent with good engineering practices. It should reflect seven attributes: commitment to systematic learning, flexibility, reversibility, auditability, transparency, integrity, and responsiveness.

Adaptive site management is seen as a more effective alternative to the traditional paradigm for hazardous site restoration, which involved a linear, unidirectional path from site investigation, to remedial actions, and eventually to site closure (NRC, 2003c). Adaptive site management is viewed as: applicable to a variety of sites and stages of restoration, providing for optimization of remedial measures, formalizing the use of monitoring, incorporating public participation, dealing with uncertainty, and stimulating development of innovative technologies (ibid.).

COMMENTARY

Although concepts of formal adaptive management for ecosystem restoration date from the late 1970s, the concept evolved, broadened, and gained currency in the 1990s, as natural resources policy makers and managers alike began to embrace adaptive management. Planners, engineers, and decision makers in other sectors and disciplines have also advocated approaches that seek to keep options open, that monitor and evaluate outcomes, and that incorporate lessons learned into future decisions. A lesson in the development and application of adaptive management-type elements in these fields beyond natural resources management is that scientists, engineers, and managers in engineering sectors are increasingly recognizing the limits of linear, deterministic approaches and predictive models. Adaptive management concepts and practices represent innovative, current thinking on resolving conflicting demands and adjusting to changing social preferences and priorities.

Adaptive management can be applied in various forms, ranging from less to more formal practices. Adaptive management entails a set of core principles, each of which can be applied in more or less elaborate forms. In deciding whether to adopt an adaptive management approach and principles, or whether more "active" or "passive" approaches should be adopted, decision makers should compare the costs and benefits of learning. Decision makers should weigh the likelihood of obtaining useful results from monitoring and the costs of obtaining them. Although adaptive approaches may be complex and may thereby frustrate some participants, many contemporary public policy problems—including many faced by the Corps—may require sophisticated approaches like adaptive

management if lasting solutions are to be identified and established.

Adaptive management may entail resistance from some stakeholders, management agencies, and elected officials. Stakeholders may be concerned with the ambiguities of the approach or with possible threats to existing structures and values, management agencies may feel that their decisions and judgment are being second-guessed, and legislators may be concerned with the costs of what may appear to be open-ended science programs. The value of adaptive management will ultimately be gauged by its ability to improve decision making by being responsive to environmental and social changes, thereby enhancing environmental and economic benefits. Adaptive management may entail a variety of detailed and useful scientific and learning exercises (e.g., development of alternative ecological and engineering models; scenario investigations by participants) and administrative processes (e.g., meetings of stakeholders). Maintaining a focus on economic and environmental goals and objectives is important to helping coordinate scientific inquiry with management decisions and stakeholder discussions and learning.

The Corps has traditionally constructed its civil works projects based on engineering principles founded upon a deterministic planning framework. Over time, however, the Corps' mission has shifted from the construction of engineering projects to managing an existing infrastructure and distributing benefits (e.g., stream flows and their associated benefits) among multiple stakeholders. Successful execution of this latter mission will require less reliance upon concepts related to linear, stable systems, and greater reliance upon expertise in ecosystem dynamics and modeling, as well as economics and other social sciences. Over time, the limits of a deterministic planning paradigm have been revealed, as have many unanticipated consequences of Corps projects. The Corps has different degrees of experience in the six elements of adaptive management identified in this chapter, and adaptive management would thus build upon some existing concepts and practices. Yet the Corps has only limited experience in integrating them within a formal adaptive management framework. A Corps of Engineers 2003 draft report prepared in connection with its Upper Mississippi River feasibility study, for example, demonstrates an understanding of adaptive management principles and challenges regarding its implementation (Lubinski and Barko, 2003). As the following chapter explains, constraints remain on the Corps' ability to implement adaptive management. Some of these constraints come from Corps planning guidance and organizational traditions, others from factors beyond the Corps, such as the influence of stakeholder groups and guidance from the administration and the Congress.

3

The Context of Corps Decision Making

The implementation of adaptive management within the Corps of Engineers will occur within a framework of legislation, agency planning guidance, a complex organizational structure, and agency tradition. Efforts at managing adaptively will also be affected by evolving relationships among the Corps, the administration and other parts of the executive branch, the U.S. Congress, and numerous interest groups. To better understand the opportunities and barriers to adaptive management in the Corps, this chapter reviews the Corps' decision making processes, its organizational dynamics, and external factors that influence the agency's missions and decision making.

PLANNING GUIDANCE

At the agency level, procedures for planning Corps of Engineers' projects are prescribed in several documents. The most important are the federal *Principles and Guidelines for Water and Land Resources Implementation Studies* (often referred to as the *"Principles and Guidelines,"* or *P&G*), and the Corps *Planning Guidance Notebook* (or PGN; USACE, 2000a), also known as ER 1105-2-100 (*http://www.usace.army.mil/inet/usace-docs/eng-regs/er1105-2-100/toc.htm*). The *Principles and Guidelines* document was approved by the U.S. Water Resources Council (WRC) in 1983. The Corps *PGN* provides direction on implementing the *Principles and Guidelines* and other Corps policy guidance concerning the planning of new water projects. Additional Corps planning guidance is provided by Corps of Engineers Engineering Circulars (EC) and Engineering Regulations (ER).

The *Principles and Guidelines* document was issued in 1983, five years after publication of Holling's 1978 volume, at a time when adaptive management concepts were somewhat novel. Moreover, many concepts in the *P&G* are derived from the earlier *Principles and Standards* planning guidance document, which was approved in 1973 (the 1983 revision also changed the status of the document from required standards

to recommended guidelines). Much of the current Corps planning guidance is thus based on concepts that pre-date the emergence of formal adaptive management strategies. The planning guidelines prescribed by the *P&G* are geared toward the planning of new civil works projects. The *P&G* document defines a six-step planning process: 1) identify a problem or opportunity, 2) inventory and forecast conditions, 3) formulate alternative plans, 4) evaluate the effects of the alternatives, 5) compare alternative plans, and 6) select a recommended plan. This is the classic, rational planning approach (Hays, 1959). The *P&G* allows the use of these steps at various planning stages and in post-construction operations decisions. Nevertheless, current Corps planning guidance is based upon a traditional emphasis on pre-project design and siting, and was not developed specifically to guide post-construction monitoring and evaluation (Jacobs, 2002). The Corps has had little experience in, and has received few administration or congressional requests for, the sort of economic, environmental, and other evaluations of post-construction outcomes of its water projects that would be essential to adaptive management.

The *Principles and Guidelines* document provides guidance for evaluating municipal and industrial water supply, agriculture, urban flood damage reduction, hydropower, transportation (inland and deep-draft), recreation, and commercial fishing projects. The *P&G* relies heavily on market-based economic models and forecasts, and relies heavily upon model-based projections. The *P&G* recognizes that risks and uncertainties attend water project planning, but risk and uncertainty analyses are not accorded an integral position in the document's recommended procedures. Furthermore, there have been substantial scientific advances in the fields of risk analysis, environmental economics, and ecosystem dynamics and modeling since issue of the 1983 *P&G* document. Finally, many benefits of adaptive management lie in the accumulation of scientific knowledge and management experience, with the aim of ultimately producing better resources management decisions. These benefits, however, are not always immediately clear and are difficult to monetize (see Box 3.1).

Adaptive management's emphasis on uncertainties, learning, and flexible policies represents a departure from the Corps' traditional planning approaches, and adaptive management principles have only begun to be incorporated into the agency's planning guidance. For example, the Corps' *Planning Guidance Notebook* makes only one direct reference to adaptive management:

> Monitoring and adaptive management. Monitoring may be necessary to determine if the predicted outputs are being achieved and to provide feed back for future projects. Cost shared post-implementation monitoring will rarely be required. If cost shared post-implementation monitoring is being considered, it must be clearly defined, justified and the period of cost shared monitoring shall not exceed five years following completion of construction. The cost of monitoring included in the total project cost and cost shared with the non-Federal sponsor shall not exceed one percent of the total first cost of ecosystem restoration features. For complex specifically authorized projects that have high levels of risk and uncertainty of obtaining the proposed outputs, adaptive management may be recommended. The cost of the adaptive management action, if needed, will be limited to 3 percent of the total project cost excluding monitoring costs (p. 3-25).

BOX 3.1
Valuing the Benefits of Adaptive Management

Many of adaptive management's benefits come in the form of better knowledge of ecosystem response to management actions. This improved knowledge reduces uncertainties and should therefore improve management decisions. Benefits of better future management decisions will be realized in the future. These benefits, however, are difficult to measure and translate into dollars, the standard metric of economic analysis. The intangible nature of these benefits stands in contrast to the direct, up-front costs of adaptive management programs, such as ecosystem monitoring programs, scientific staff, and institutional support. Gaining political approval and funding for adaptive management may be difficult if traditional, standard economic analysis cannot be or is not done. Clear articulation of the benefits of adaptive management to stakeholder groups, decision makers, and budgeters, may thus constitute a challenge to persuading skeptics of the value of the concept. Failing to learn from past experiences may entail costs in the form of inefficient operations and protracted controversies that spring from policies that have not been adjusted to changing conditions and social preferences.

Specific guidance regarding monitoring for small projects carried out under the Corps programmatic authorities makes essentially the same statement.

Despite the fact that the adaptive management concept is not widely reflected in the agency's planning guidance, many Corps staff have knowledge of adaptive management principles, and some (especially in the Corps Jacksonville district office) have direct experience with its implementation. The following sections discuss implications of the Corps' organizational structure, staffing, and other factors for promoting adaptive management practices.

INTERNAL ORGANIZATIONAL ISSUES

Adaptive Management Definitions and Applications

As part of this study, anecdotal evidence was gathered during meetings and site visits with Corps staff involved in various aspects of adaptive management. Based on that information, it appears that adaptive management principles are not being consistently employed throughout Corps district offices. Given the agency's decentralized structure, this is not surprising; furthermore, adaptive management guidance should allow flexibility so that programs can be tailored to local and regional settings. Nevertheless, basic concepts should be consistently employed across Corps projects and throughout the agency, as a lack of consistency of definitions and practices can limit the effectiveness of adaptive management efforts, as well as the ability of the organization to learn from experiences across its district offices.

The Corps appears to view adaptive management primarily as a vehicle for ecosystem restoration, which is understandable given the roots of adaptive management and its applications to date. However, opportunities for adaptive management applications in other mission areas may be overlooked. There are other sectors, such as navigation and waterway traffic management, in which adaptive management may be useful not only in effecting changes to evolving conditions, but also in helping better integrate project operations and program areas. Moreover, adaptive management offers a framework for integrating programmatic areas such as navigation and ecosystem restoration. Adaptive management would encourage the consideration of navigation, ecosystem restoration, and flood risk management as part of a single, holistic system.

Decentralized Structure

The Corps' organizational structure also affects its ability to implement adaptive management. The Corps is a highly decentralized organization, with 41 district offices, all of which function primarily independent of one another. These offices conduct Corps reconnaissance and feasibility studies for new water resources projects, and they employ the majority of the agency's staff. One advantage of this structure is that district offices may have greater flexibility to pursue innovative efforts and novel actions tailored to local conditions and preferences. A drawback of this structure is that these offices are focused largely on planning their own new projects and working closely with local project sponsors, without benefiting from the knowledge and experience of colleagues in other district offices. There are limited incentives and resources, and few precedents or traditions, for district offices to seek information from one another or from experts outside the organization, or to communicate lessons from their experiences throughout the organization. Although many Corps district offices and personnel are pursuing adaptive management activities, these experiences are not being explicitly shared throughout the agency.

Human Resources and Staffing

Meeting the challenges associated with adaptive management is likely to require not only a Corps staff that possesses broad, interdisciplinary expertise and experience, but also input and assistance from organizations and experts from outside the agency. As part of this study, organizational charts of the Corps St. Paul (MN), Omaha (NE), and Jacksonville (FL) district offices were reviewed, and this panel made site visits to St. Paul and to Florida, where the panel spoke with Corps staff and other experts involved in the Florida Everglades restoration project. This section lists some observations based on these documents and meetings.

St. Paul District

Key positions related to adaptive management in the Corps St. Paul district office are in the four branches under the Planning, Programs, and Project Management Division. Most important is the Environmental and Economic Analysis Branch, which has 18 professional positions, includ-

ing the branch chief. There are nine natural scientists (of which eight are biologists), three cartographers, two economists, one "multi-disciplinarian," one historian, and one archaeologist. Together the other three branches have ten multi-disciplinarians, five program analysts, three chiefs, one landscape architect, and one operations and management program manager.

Omaha District

The Omaha district office is organized differently: there is no Planning, Programs and Project Management Division, and hence no Environmental and Economic Analysis Branch. The Omaha office is divided into four divisions: Engineering, Construction, Real Estate, and Operations. The Construction and Real Estate divisions appear to have no staff related to project operations. In the Engineering Division, the two key branches related to adaptive management are the Hydrologic Engineering Branch and the Geotechnical and Engineering Sciences Branch. Both are staffed primarily by engineers. In the Hydrologic Engineering Branch the main exception is the Water Control and Water Quality Section that includes a biologist, an ecologist, and a limnologist. The sections in the Geotechnical and Engineering Sciences Branch most relevant to adaptive management have some geologists and chemists, but apparently no biologists or social scientists.

The operations division is divided into project offices that correspond to some of the Missouri River mainstem dams: Big Bend, Fort Peck, Fort Randall, and Garrison. Although each of these offices has a natural resources section, the emphasis in each case appears to be on park management. Big Bend thus has a supervising natural resource specialist in the project office and a natural resource management specialist and two natural resource specialists/rangers in the Natural Resources Section. Fort Peck (divided into Fort Peck Lake and the Fort Peck Office) has a similar staffing arrangement, with an additional resources specialist/ranger. At Fort Randall, the Natural Resources Section is composed primarily of rangers, plus one natural resource specialist and two natural resource specialists/rangers, versus four natural resource specialists and three natural resource specialists/rangers at Garrison. No social scientists are listed. Elsewhere, no economists or lawyers were included in the staff list; indeed, in the entire district office, the only possible social scientist was a geographer in the Applications and Planning Branch under the Executive Office.

Jacksonville District

Sections of the Jacksonville district office most relevant to adaptive management are the Constructions-Operations, Planning, Restoration Program, and the Regulatory divisions. The Constructions-Operations Division contains the Comprehensive Everglades Restoration Plan (CERP) Management Branch, while the four branches in the Planning Division are Socio-Economic, Environmental, Plan Formulation, and Ecosystem Restoration. The Restoration Program Division also has four branches: South and Central Florida Restoration, RECOVER (Restoration, Coordination and Verification), and Restoration Programs Management. The Regulatory Division divides Florida into four branches within an overarching Enforcement Branch.

The Jacksonville district organizational chart reflects the Corps' roles in the Comprehensive Everglades Restoration Program, as branches such as the RECOVER and CERP Management Branches, which have adaptive management-related functions, have been established. Nonetheless, staffing and institutional gaps remain. With the exception of the Socio-Economics Branch in the Planning Division, the social science expertise that could help address issues related to Florida's rapid population growth is limited. Biologists are still based primarily in the Regulatory Division, although they also have a presence in the Planning Division. The position of Chief in the CERP Management Branch was vacant in 2003 when this study was being conducted.

Summary

In many ways, adaptive management represents a departure from traditional Corps planning approaches and disciplinary strengths. These strengths have been in the realm of engineering expertise and the construction and operation of civil works projects. The Corps is in the midst of broad shift toward increased emphasis on operating a large, existing infrastructure, which controls a large portion of the nation's hydrologic systems and distributes significant benefits. The Corps must maintain its engineering expertise in order to safely operate this infrastructure. But sound management of Corps projects today also calls for expertise in fields such as ecology and economics.

Adaptive management is consistent with this broadening mission and it represents a promising means for making better decisions under uncertainty and facilitating stakeholder cooperation and input. It aims to fuse

knowledge and understanding of economics and other social sciences, engineering, and ecology. Much of the literature on the concept to date has emphasized ecological sciences, but adaptive management requires social sciences knowledge for project evaluation and related activities. Given the importance of communicating with stakeholders on complex and controversial topics, it could also entail the use of experts in topics such as visualization and facilitation. Just as important as broadening disciplinary expertise is the incorporation of these broader perspectives within Corps decision making. Enlisting experts in social and ecological sciences, or commissioning studies in these areas, is of little use if the agency does not have the appropriate capacity to meaningfully incorporate these perspectives and knowledge into the project planning and management cycle.

A review of adaptive management efforts and staffing arrangements at three Corps district offices suggests that a broader range of personnel and disciplinary perspectives should be included within all phases of project management in order to implement adaptive management within the agency. For example, some Corps staff members are occasionally involved in projects and tasks that transcend their expertise, such as when engineers are asked to conduct economic analyses or to facilitate public meetings regarding controversial studies or projects. Moreover, there is no evidence that adaptive management efforts in district offices are proceeding consistently in accord with a set of guiding principles, or with the sharing of experiences and knowledge across district offices or throughout the agency. Not every Corps office need employ experts from a wide range of disciplines, but the Corps needs broader expertise that its staff can turn to in implementing and sustaining adaptive management practices. A small center specializing in adaptive management could house an interdisciplinary team to provide advice to all Corps offices and to synthesize results of Corps adaptive management efforts from across the nation.

FACTORS EXTERNAL TO THE CORPS

Congress and the Administration

Political Relations

The Corps of Engineers operates within constraints imposed by the Congress and the administration. Since the first Rivers and Harbors bill

of 1824, the Corps has been politically responsive to Congress (Clarke and McCool, 1996; Maass, 1951). Members of Congress have long funneled money and jobs to their home districts via Corps civil works projects, and have endorsed, supported, and reinforced structural modifications of waterways (Ferejohn, 1974; Maass, 1951). Congressional representatives, however, often have opposing points of view and there are indications that the Corps' traditional breadth of support in the Congress is diminishing. As a result, the Corps today often finds itself caught between opposing points of view held by different congressional representatives (see, for example, the Missouri River case study in Chapter 4).

The president wields great influence on the Corps, particularly through the Office of Management and Budget (OMB), as all Corps planning studies must ultimately receive OMB approval. Although presidents have often deferred to congressional preferences with regard to water project construction, there have been notable exceptions. In the late 1970s, for example, President Jimmy Carter attempted to terminate several proposed Bureau of Reclamation and Corps projects, only to inspire a vehement agency and congressional response. More recently, the OMB, responding to instructions from President George W. Bush, killed a long-standing proposal for a jetty project in North Carolina. Given the influence of the Congress and the administration in setting program priorities, budgetary constraints, and the like, successful implementation of adaptive management programs will require support of the Congress and the administration.

Priorities and Objectives

There are literally hundreds of public laws, congressional committee reports, and executive branch guidance to which the Corps must respond. Some of the objectives of these laws and reports lack clarity. Project objectives, for example, are often framed in terms of qualitative goals such as "restoring ecosystem health," recognizing a "nationally significant ecosystem," or "protecting values." Others are in tension with one another, requiring the Corps to identify priorities and trade-offs. The Corps also operates under the scrutiny of multiple stakeholders with competing or mutually exclusive objectives, making it difficult for the Corps to implement decisive management actions in either direction.

Adaptive management recognizes that stakeholder differences are inevitable, and it does not seek to eliminate those differences before proceeding. As mentioned, adaptive management does not aim to create a

"master plan" to be rigidly adhered to. But without some agreement upon and clarity of objectives, it can be difficult to determine whether management actions are having desirable effects. This, in turn, can obstruct the feedback processes (e.g., learning, adjustment, subsequent actions) within adaptive management. Water resources experts have long recognized the importance of flexibility within water resources program objectives. As early as 1938, for example, the (former) National Resources Committee noted the importance of establishing objectives (as well as an adaptive approach) in one of its recommendations for more efficient water management: "Adherence to a national over-all plan, revised and adjusted year by year in light of new knowledge (assiduously and continuously developed) and of shifting conditions" (National Resources Committee, 1938). In a more recent example from the Upper Mississippi River, the Upper Mississippi River Basin Association noted the problems of multiple mandates and a lack of vision in a 1995 report:

> The issue is not that the Upper Mississippi River lacks programs, projects, studies, regulatory authorities, and management activities with the potential for addressing many of the current problems. Rather, there is no unifying principle or focus for integrating those efforts (UMRBA, 1995).

A previous National Research Council committee noted the problems associated with an inability to distill clear management objectives for Glen Canyon Dam and Colorado River management:

> The Strategic Plan should recognize the limitations of the current, pluralistic situation. It should present a strategy for moving toward a set of common objectives . . . The Center . . . should work with the Technical Work Group to develop a revised set of management objectives (NRC, 1999).

Finally, a National Research Council committee charged to review Missouri River ecosystem science and adaptive management concluded that a Missouri River Protection and Recovery Act should be passed to "ensure clarity regarding authority . . . ." (NRC, 2002).

Rarely, if ever, will congressional representatives, stakeholders, managers, and decision makers reach clear consensus on ultimate objectives, or a "vision," for managing large aquatic, river, or coastal systems. In such instances, adaptive management, through advanced scientific

knowledge and stakeholder dialogue, can be used as a vehicle to help identify and clarify objectives as the program proceeds. Adaptive management should be used as a means to foster stakeholder collaboration, identify and discuss differences, and adjust program goals and direction in accord with new information and shifting preferences. Social goals and priorities change over time. When objectives are established, as the National Resources Committee noted in 1938, adjustments will eventually be required. In the process of establishing new objectives, disputes between interest groups who favor the status quo, and those who favor change, are virtually certain. Whatever course is chosen, discussion of objectives and trade-offs should be a part of adaptive management, with an understanding that clarification of objectives and priorities is important, but that they are likely to require future review and revision. In larger systems, such as inter-state river basins, guidance from the administration and Congress may be necessary to clarify responsibilities and resolve conflicts that a line agency like the Corps cannot unilaterally resolve.

Inter-Agency Relations

When adaptive management programs are initiated in large, complex ecosystems, and as the geographic scale of management increases, more management organizations and levels of government are likely to become involved. Implementing adaptive management across organizational and political boundaries requires communication, cooperation, and a means for clarifying responsibilities among federal, state, and local governments with responsibility for the various places and activities involved.

At the federal level, the Corps often interacts with the Environmental Protection Agency, the Fish and Wildlife Service, the U.S. Geological Survey, NOAA Fisheries, and the National Park Service, all of which have different mandates and traditions. Interagency cooperation can be problematic and may constitute an obstacle for adaptive management: "Experimental management planning has floundered in complex institutional settings like the Florida Everglades, Columbia River, and Upper Mississippi River, where management, research, and policy change involve collaboration among several agencies with complicated, overlapping historical responsibilities and legal mandates" (Walters, 1997). Clarification of agency lines of authority and responsibilities provided by the administration and the Congress would be helpful in delineating

agency programs and useful in promoting adaptive management. Adaptive management's emphasis on collaboration also serves as a framework for enhancing interagency cooperation.

Existing Authorities

Existing authorities for the Corps' civil works program and projects are often inimical to the execution of adaptive management principles. More importantly, the present legal framework governing completed projects creates barriers to adaptive management. Since the Water Resources Development Act of 1986, Corps civil works projects constructed for purposes other than navigation are authorized to require all post-construction project-related responsibilities, including operations, maintenance, repair and rehabilitation, to be carried out by a non-federal sponsor. Federal direction and performance monitoring is covered in an operating manual provided by the Corps to the sponsor, and the Corps makes periodic inspections of projects to review compliance with manuals. Subsequent modifications of either project features or project operations typically require completion of a cost-shared study and authorization of a project modification. If the Corps is to become more actively involved in adaptive management, changes in existing authorities will be required in order to give the Corps a greater role in post-construction activities.

Exceptions to this rule are the "Section 1135" authority from the 1986 Water Resources Development Act, "Section 216" authority from the 1970 Flood Control Act, and the Comprehensive Everglades Restoration Project (CERP) authorized by the Water Resources Development Act of 2000. These authorizations allow the Corps to review and modify existing operations in response to significantly changed conditions without seeking additional congressional authorization. In recognition of the uncertainties inherent in this multiple-purpose environmental restoration and water supply project, the Corps requested specific authorization for adaptive management for the CERP. Consistent with this concept of life-cycle project evolution, Congress authorized continuing federal participation in post construction project decision making, as well as a 50/50 cost sharing of project costs. The CERP authorization is a model for future authorizations of projects with potentially significant ecological consequences in the form of either project-provided services or adverse project impacts, whether mitigated or unmitigated. A continuing project authority that allows appropriate project modifications to achieve the

original goals, or to adapt to evolving public values and new scientific understandings of ecological processes, without the need to seek a new project-specific authorization, would be an important step toward adaptive management of Corps projects.

Small Projects Authority

Several small project authorities allow the Corps to implement projects without the need to obtain a specific authorization from Congress. Section 216 of the 1970 Flood Control Act authorizes the Corps to review and modify existing operations in response to significantly changed conditions, without seeking additional congressional authorization. Section 1135 of WRDA 1986 (as amended in Public Law 99-662) authorizes the Secretary of the Army to modify existing Civil Works project structures and operations to improve the quality of the environment in the public interest. Modifications must be feasible and consistent with authorized project purposes. Section 206 of WRDA 1996 authorizes the Secretary to carry out projects for aquatic ecosystem restoration and protection if the Secretary determines that the project will improve the quality of the environment, is in the public interest, and is cost-effective. Corps policy governing these projects affirms the primacy of ecological justifications, as opposed to any recreational or other economic justification.

Although these authorities allow for some degree of flexibility and adjustments to management actions, they were not explicitly designed to help the Corps implement adaptive management approaches. These authorities also lack the specificity required to adequately consider contemporary planning approaches (e.g., nonstructural alternatives) and realities (e.g., a greater emphasis on better management of existing infrastructure vs. more new project construction). Corps policy, however, narrows even these limited openings by restricting monitoring to no more than three years (this policy also appears to erroneously equate adaptive management with ecosystem monitoring). The Corps does not require periodic evaluation of completed projects to determine whether structural modifications or operational changes are needed to improve project performance. Instead, Corps policy and management philosophy for these small projects parallels its guidance for specifically authorized non-navigation projects (with the exception of the Comprehensive Everglades Restoration Project). The agency's objective is to plan and implement projects in partnership with a non-federal entity. After construction,

Congress typically expects the Corps' job to be done; the non-federal partner is expected to assume responsibility for all project activities and costs, including future capital expenditures. A new authority that directs the Corps toward a greater emphasis on flexible, adaptive management strategies would be useful in backing the agency's efforts in adaptive management. The new authority should not represent a "blank check," but rather should contain some specificity that helps the Corps balance its environmental, flood management, and navigation-related responsibilities (the report from the 216 studies coordinating committee reviewed this issue in greater detail and provides specific provisions regarding a new study authority).

Budgeting and Financial Issues

The Corps budget for operations is controlled by the administration and the Congress, which have traditionally placed a higher priority on expenditures for capital works construction than for science-based management or project evaluations. Furthermore, most projects require both individual authorization and annual appropriations. Authorized programs may thus in reality be funded at well below authorized levels. When money is available for ongoing programs such as adaptive management, expenditures are limited in other ways by the Corps' governing legislation and regulations. Total expenditures may be limited, cost-sharing (25 percent or 35 percent) by non-federal partners is typically required (NRC, 1999), and non-federal sponsors may be required to assume all costs for post-construction operation and maintenance. Cost-sharing requirements for Corps of Engineers projects, many of which were specified in the 1986 Water Resources Development Act, may be hindering progress toward adaptive management in at least some locations. In the Upper Mississippi basin, for example, the Corps is in the midst of a feasibility study for the Upper Mississippi River-Illinois Waterway. Within the study, the Corps is considering a variety of possible ecosystem restoration projects. Some of these options would entail cost-sharing arrangements with private land holders. The Upper Mississippi River basin states, however, often view these financial obligations as a constraint. For example, the states feel that "measures to address the ongoing and cumulative impacts of the navigation project should be 100 percent federally funded" (UMRBA and GLC, 2003). Chapter 4 includes details of the Upper Mississippi and other adaptive management programs in which the Corps has participated.

Stakeholder Participation

Passage of the 1986 Water Resources Development Act (WRDA 86) had great implications for stakeholder participation in Corps projects, as it mandated more stringent cost-sharing requirements for local sponsors of Corps projects. WRDA 86 has resulted in local stakeholders—most importantly, the paying co-sponsor—taking a greater interest in project design and implementation. Increased stakeholder participation, however, provides both opportunities and limitations with regard to adaptive management. For example, project co-sponsors typically have a specific project in mind, and thus naturally seek timely construction in order to minimize costs. Local sponsors may not wish to provide additional resources for post-construction monitoring, or discuss prospective operational changes with other stakeholders, that would contribute to adaptive management. The willingness to consult with other stakeholders depends on the ability of these others to disrupt activities (in the case, of the Corps and a local co-sponsor). Local sponsors may view participation of other stakeholders as a way to engage in constructive, open discussions aimed at reducing tensions and objections.

Adaptive management experts and practitioners today widely recognize the importance of open and vigorous stakeholder participation (Shindler and Cheek, 1999). The issue of involving interest groups in water management decisions reflects a long-standing, ever-present tension between expert/science-based decision-making and democratic/citizen-based decision making. For much of the agency's history, the Corps and the nation adhered to an expert-based model of decision making (Hays, 1959). But in today's operating context, the complexities and uncertainties of natural resources management—and thus the limits of purely expert/science-based decision making—are better understood, and interest groups today seek a greater role in environmental and natural resources management.

Interest groups, agencies, and other participants may resist the implementation of adaptive management approaches. They may perceive that adaptive management puts their interests at risk. Furthermore, multipurpose projects have multiple stakeholders with different and often conflicting expectations. Professional planners and managers may feel that adaptive management implies a lack of confidence, and would reveal only bad news regarding deterministic projections of project performance. Such tensions are often inherent in natural resources management

programs, and adaptive management is not an elixir that will resolve all of them. But by promoting discussions within a collaborative framework, adaptive management promotes the search for common ground and goal definition and refinement.

Although there may be limits to the value of stakeholder participation (Kenney, 2000), such participation in water management is increasingly promoted in the U.S. and around the world (Box 3.2). The approach is seen by many as a vital component of sound water resources decision making and is today widely viewed as a staple of resource management programs. The Corps has promoted stakeholder participation via public meetings and "listening sessions" across the nation. Resolving competing interest group demands, and balancing its federal interest responsibilities with a desire to be responsive to the public, represents a never-ending tension and challenge to the Corps.

The Corps recognizes the importance and value of stakeholder participation, and deserves credit for its strong efforts in convening public meetings and other fora to promote stakeholder input. But stakeholder involvement represents challenges, as well. Stakeholder opinions may vary widely and be narrowly based on a single issue, and some stakeholders may support policies and actions that are not scientifically or legally feasible. Responding to some stakeholder opinions may pose inconsistencies with the Corps' federal stewardship responsibilities. Stakeholder participation has both positive and negative implications for adaptive management efforts. A review of these experiences and their implications would be useful in developing agency-wide guidance for stakeholder participation in adaptively managed projects (the 216 study report on analytical methods also discusses the issue of stakeholder participation, devoting an entire chapter to this topic).

COMMENTARY

The ability to implement adaptive management within the Corps of Engineers is affected by factors both within and outside the organization. Within the organization, adaptive management represents a departure from the Corps' traditional culture, as well as from the planning methods embodied in the *Principles and Guidelines*. Factors beyond the Corps, notably the roles of Congress and the administration, and stakeholder groups affected by Corps projects, also affect implementation of adaptive management. Congress and the administration ultimately control the purse strings on Corps programs. Progress toward adaptive management

BOX 3.2
Experiences in Stakeholder Participation

The value of stakeholder participation in water resources management decisions has been demonstrated within Australia's Murray-Darling Basin Commission (MDBC). The MDBC has promoted stakeholder involvement through multiple means and programs, including the creation of an Independent Community Engagement Panel (which reports to a Ministerial Council) and the commissioning of an independent Stakeholder Profiling Study, which included interviews with hundreds of citizens (Nancarrow and Syme, 2001). The MDBC's views on the importance of stakeholder input are reflected in a comment on the Stakeholder Profiling Study: "It is undeniable that sustainable natural resources management is inextricably linked with the views and attitudes of community stakeholders—successful natural resource initiatives rely not only on scientific evidence but community awareness, acceptance and involvement" (http://www.mdbc.gov.au/whatson/stake-h.html). The MDBC's efforts in communicating with stakeholder groups may also have created the foundation for an agreement known as "The Cap," which imposed a limit on additional water that could be diverted from the rivers in the Murray-Darling basin, and included an independent audit of the agreement's effectiveness.

Within the U.S., the Deschutes Resources Conservancy provides an example of broad-based participatory partnership, as well as one involved in large-scale adaptive management. A sub-basin of the Columbia River system, Oregon's Deschutes River Basin covers 10,700 square miles. Its population of about 150,000 in the mid-1990s includes several towns, five Bureau of Reclamation dams serving 11 irrigation districts or companies, and the Warm Springs Native American Reservation. Arising from an initiative of the Confederated Tribes of Warm Springs and Environmental Defense, the Conservancy was created in 1996. It describes itself as the "first non-profit corporation to bring together State, Federal, Tribal and local government representatives with private stakeholders to carry out basin wide ecosystem restoration." Recognized by Congress, which authorized one million dollars annually over the first five years on a cost-sharing basis, it operates by consensus while giving priority "to voluntary, market-based economic incentives for ecosystem restoration." To date over twenty restoration projects have been supported (see EDF, 1995, and http://www.deschutesrc.org/about/about.htm; accessed January 29, 2004, for additional information)

Stakeholder involvement requires careful consideration of who should be stakeholders and how those stakeholders should be involved. To identify key stakeholders, the World Commission on Dams recom-

Continues

Continued BOX 3.2

mended analysis based on a "recognition of rights" and an "assessment of risks" approach at the commencement of the decision-making process (WCD, 2000). Such an analysis would identify existing rights, broadly defined to include human rights along with property, resource access and livelihood rights. It would also consider constraints that might restrict involvement of certain key stakeholders, along with capacity building where necessary.

There is emerging agreement on principles for stakeholder involvement. Although the process may vary from case to case, it is fundamental that it be agreed upon by stakeholders and the project authority rather than superimposed by the latter on the former. The World Commission on Dams suggested that a stakeholder forum be convened for that purpose once key stakeholders have been identified. From the start, stakeholders should know what the objectives of their involvement are, the nature of their influence, how decisions will be made, and what mechanisms exist for conflict resolution.

with the Corps and with regard to its projects can only be as fast as Congress and the administration will allow. Citizens and interest groups also play important roles. Many influential groups have a strong interest in retaining status quo management practices and the current patterns of distribution of benefits from the nation's river and coastal systems. Adaptive management's promise of long-term benefits through increased knowledge and better management can be a hard sell in a nation and political system geared toward realizing short-term returns. Although progress toward enhancing economic or environmental benefits has to date been limited in the Corps' initial forays into adaptive management, some of these efforts represent steps in the right direction, recognizing that none can at this point be regarded as fully successful.

A shift toward adaptive management is consistent with recognizing inevitable changes in the settings and objectives of Corps projects, uncertainties in the outcomes of Corps projects, an increasing pace of social, economic, and scientific changes, and the importance of devising strategies to cope with and benefit from change. In many instances, management and outputs of Corps projects have not reflected changing eco-

nomic and social values in the U.S.; one manifestation of this problem is increasing criticisms and tensions surrounding many Corps projects. If the Corps is to be properly prepared to meet water management objectives in the twenty-first century, the agency, with support of the Congress and the administration, must devise management approaches that can better adjust to changing conditions. The basic requirement for adaptive management to establish management objectives (see Chapter 2) may initially appear to be in conflict with the notion of ever-changing social values and priorities. This need not be the case, however, as adaptive management programs should include periodic reassessment of objectives based on both shifting social priorities and on new environmental and economic information. Clearer advice from the administration and the Congress with regard to water management priorities and direction would be useful in instances in which a line agency like the Corps is unable to duly resolve conflicts or identify preferred alternatives.

Another reason why the Corps is correct to move toward an adaptive management paradigm is that the future roles of the agency will be vastly different than its past roles. The Corps of the future will not be the nation's dam-building agency as it was during the 1950s and 1960s. It is unlikely that many more large U.S. federal dams will be constructed. But the Corps will continue to operate a multi-billion dollar infrastructure that controls a large portion of the nation's hydrologic systems. The agency today is thus in a transition from a past, construction-based mode to a future, management-based mode. In a management-based setting, the alternative to proactive, science-based, collaborative water management is reactive management, with fixed policies and practices not designed for evaluation and change. The latter is likely to lead to organizational rigidity and increasing conflict. Although it is by no means a panacea for resolving conflict, restoring degraded ecosystems, or eliminating uncertainties associated with complex decisions, adaptive management currently represents the most promising path for the Corps to better manage its existing infrastructure.

4

Case Studies of Adaptive Management

This chapter reviews some of the Corps' initial efforts in implementing adaptive management principles, most of which were initiated during the mid-1990s. These case studies include the Florida Everglades, the Missouri River Dam and Reservoir System, the Upper Mississippi River, and coastal Louisiana. A case study of the Adaptive Management Program at the Glen Canyon Dam and Colorado River ecosystem, in which the Corps is not involved, is included for comparative purposes, as there is a relatively long record of applying adaptive management principles to managing the Colorado River. A case study on the Columbia River, the site of one of the earliest adaptive management applications in a large U.S. river system (Lee, 1993), was considered but not included. Although the Corps has responsibilities for navigation and dam operations on the Columbia River, it has had only a relatively small role in formal adaptive management efforts, which mainly involved the Northwest Power Planning Council (renamed the Northwest Power and Conservation Council in 2003) and federal and state resources agencies. The settings of these case studies vary in terms of spatial scale, biophysical features, inter-agency relations, economic activities, and stakeholder preferences. Lessons from experiences in this breadth of settings may reveal general principles regarding potential barriers, useful management actions, or inter-agency relations that merit consideration in establishing and managing adaptive management programs.

FLORIDA EVERGLADES

The Everglades ecosystem (Figure 4.1) stretches from Florida's Lake Okeechobee southward to the Florida Reef Tract. The pre-settlement ecosystem featured the slow movement of surface waters to the south and the west, which eventually emptied into the Atlantic Ocean and the Gulf of Mexico. This low-relief, marshy ecosystem is often referred to a

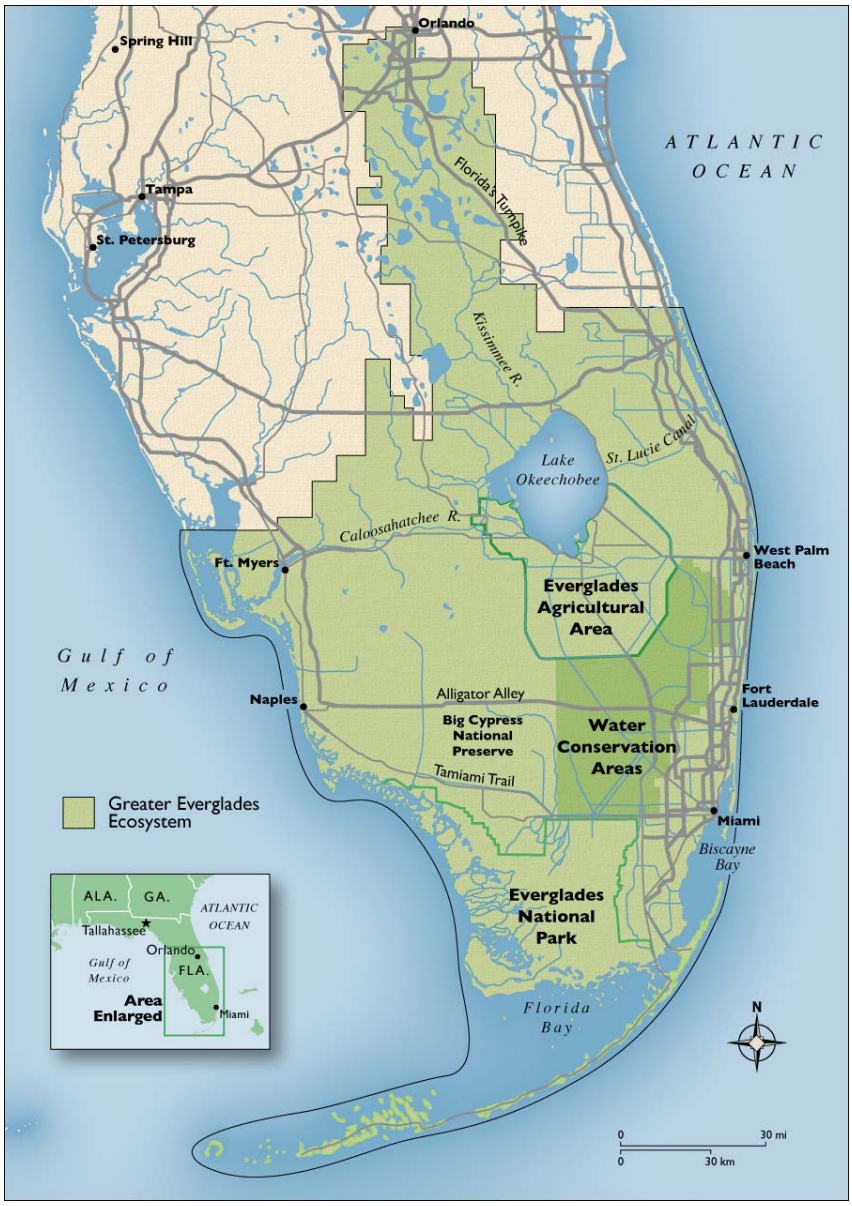

Figure 4.1 Greater Everglades Ecosystem.

"river of grass," a term coined by Marjorie Stoneman Douglas in her famous book on the Everglades ecosystem. Her book was published in 1947, the same year Everglades National Park was established. The ecosystem experienced significant human-caused alterations as early as the mid-eighteenth century, when parts of it were drained to promote agriculture and settlement. In 1907 the Everglades Drainage District was created (Blake, 1980) and by the early 1930s, 440 miles of drainage canals had been constructed in the Everglades (Lewis, 1948). Concerns about ecological degradation of the Everglades were raised as early as the 1920s, and by the time Stoneman wrote her book, the ecosystem had been extensively altered. These ecological changes continued in the late 1940s, when huge floods in 1947-48 across south Florida led Congress to establish the "Central and Southern Florida Project for Flood Control and Other Purposes." This initiative led to accelerated ecological changes in the Everglades, as the project entailed levees, water storage, improvements of conveyance channels, and large-scale pumping to supplement drainage. All these projects helped channel water away from the Everglades in an effort to reduce floods, support agriculture, and promote settlement. The project also entailed the construction of a 100-mile perimeter levee separating the Everglades from coastal urban development. These hydrological changes were substantial and have been linked to, for example, declines in avian species and the listing of dozens of animal and plant species as federally threatened or endangered.

In response to these declining ecological trends in the Everglades, the federal Water Resources Development Act of 1992 authorized a comprehensive review of the Central and Southern Florida Project. In 1993, the Corps of Engineers and the South Florida Water Management District began a Comprehensive Review Study (known as the "Restudy") to determine the feasibility for modifications to improve the sustainability of South Florida (USACE and SFWMD, 2002). The Restudy led to publication of the Comprehensive Everglades Restoration Plan (CERP), a document that was approved in the Water Resources Development Act of 2000. Congress approved the comprehensive plan with an estimated cost of some $7.8 billion (1999 dollars) as a framework for planning projects to restore a major portion of the historic Everglades, including Everglades National Park, while meeting other water-related needs (e.g., water supply, flood management) of South Florida through 2050. In approving the plan, Congress included adaptive management (referred to as adaptive assessment) as an authorized activity, at a cost of $100 million, and provided for a 50/50 split of these costs between the federal government and the State of Florida. This authorization is notable for two rea-

sons. First, adaptive management was recognized explicitly as a water management approach for the first time in a civil works project authorization. Secondly, the Corps was authorized to share in the costs of all operations and maintenance costs of CERP, including the costs of "adaptive assessment and monitoring."

The Comprehensive Restoration Plan was developed by the Corps of Engineers in partnership with the South Florida Water Management District, and with participation of several federal and state agencies and extensive public and stakeholder involvement. Its purpose is "to restore, preserve, and protect the South Florida ecosystem while providing for other water-related needs of the region, including water supply and flood protection (WRDA 2000, Title IV, Section 601(b), Public Law No. 106-541)." The plan is to be implemented to ensure protection of water quality, restore some degree of pre-settlement hydrologic conditions (including reductions of freshwater flows to several estuaries), improve environmental conditions of the South Florida ecosystem, and achieve and maintain benefits to the natural and human environments (as described in the plan) for as long as the project is authorized (http://www.evergladesplan.org; accessed January 28, 2004). The plan is designed to provide over 1,100,000 acre-feet of additional water annually to the environment and human uses. About seventy percent of the water would be devoted toward environmental objectives, and the remainder would be devoted to economic purposes—largely for domestic use by the additional six million residents expected to inhabit the region served by the project by 2050 (USACE, 1999).

The Comprehensive Everglades Restoration Plan is not based on a traditional Corps feasibility study, but is largely a conceptual plan encompassing 68 individual projects. Major components of the plan involve sophisticated technical aspects, including large-scale use of aquifer storage and recovery for multiyear subsurface retention of captured surface water (NRC, 2001a), and subsurface seepage barriers to prevent loss of the captured water to the system as it is being stored and delivered (these techniques are not well-tested on this scale). Because of the plan's size and complexity, it will take many decades to implement, and congressional authorizations to construct and operate the plan's major elements will depend upon submission of detailed feasibility-level studies for individual projects. Additional modeling and design is underway to provide detailed project recommendations, and pilot projects are being developed to address technical uncertainties. Adaptive management will be critical to the plan's evaluation and improvement. Key aspects of the

plan include additional water storage and water supply, improved water quality, and increased connectivity within the components of the hydrologic system. These features include more natural hydropatterns, including wet and dry season cycles; natural recession rates; surface water depth patterns; and, in coastal areas, salinity and mixing patterns characteristic of the natural system.

Adaptive Management in the Restoration Plan

The Programmatic Regulations for the Comprehensive Everglades Restoration Plan contain definitions regarding adaptive management within the plan:

> *Adaptive management* means the process of improving understandings of the natural and human systems in the South Florida ecosystem, specifically as these understandings pertain to the goals and purposes of the Plan, and to seek continuous improvement of the Plan based upon new information resulting from changed or unforeseen circumstances, new scientific or technical information, new or updated models, or information developed through the assessment principles contained in the Plan, or as future authorized changes to the Plan are integrated into the implementation of the Plan.
>
> *Assessment* means the process whereby the actual performance of implemented projects is measured and interpreted based on analyses of information obtained from research, monitoring, modeling, or other relevant sources (68 Fed. Reg. 218, 64,199-64,249).

According to the proposed regulations, the purposes of the adaptive management program are to: (a) assess responses of the system to implementation of the plan; (b) determine whether or not these responses match expectations, including the achievement of the expected performance level of the plan, the interim goals and the targets for achieving progress towards other water-related needs of the region provided for in the plan; (c) determine if the plan, system or project operations, or the sequence and schedule of projects should be modified to achieve the goals and purposes of the plan or to increase benefits or improve cost effectiveness; and (d) seek continuous improvement based upon new in-

formation resulting from changed or unforeseen circumstances, or new scientific or technical information. Adaptive management activities are to be carried out by interagency and interdisciplinary scientific and technical teams organized under the Restoration Coordination and Verification program, or RECOVER (*http://www.evergladesplan.org/pm/recover/recover.cfm*; accessed January 28, 2004). These teams are established by the Corps of Engineers and the South Florida Water Management District to assess, evaluate, and integrate projects, with the goal of achieving system-wide goals and purposes. Adaptive management activities constitute only some of the many tasks within RECOVER. The RECOVER teams are not decision-making bodies. They make recommendations to the Corps and to the South Florida Water Management District, the latter which both implements and manages the project. The regulations indicate that these organizations are to use reports from RECOVER, reports of an independent scientific review panel (to be convened by the National Research Council), or other appropriate information for improving the plan by modifying its operations, goals, physical components, or the sequence of their implementation. An Initial Restoration Plan update (ICU) is planned, in which the plan is to be reconsidered and redefined.

The General Accounting Office (2003) reviewed interagency science coordination related to the restoration of the South Florida ecosystem. From 1993 through 2002, federal and state agencies spent $576 million to conduct mission-related scientific research, monitoring, and assessment. However, the GAO found that the "key tools needed for effective adaptive management have not yet been developed, including (1) a comprehensive monitoring plan for key indicators of ecosystem health and (2) mathematical models that would allow scientists to simulate aspects of the ecosystem and better understand how the ecosystem responds to restoration actions" (GAO, 2003). It was further noted that: "without such tools, the process of adaptive management will be hindered by the fact that scientists and managers will be less able to monitor key indicators of restoration and evaluate the effects created by particular restoration actions" (ibid.).

Even more recently, adaptive monitoring and assessment within the Comprehensive Restoration Plan was reviewed by the National Research Council Committee on Restoration of the Greater Everglades Ecosystem (CROGEE). The report from that committee concluded that: (1) the monitoring needs must be better prioritized; (2) system-wide indicators of ecosystem status should be developed to add to the present more nar-

rowly defined indicators; (3) region-wide assessment of external human and environmental drivers (such as population growth, land-use changes, water demand and sea level rise) is needed; (4) monitoring, modeling and research should be integrated to promote learning within an adaptive management framework; and (5) the process for scientific feedback to the restoration plan needs more consideration (NRC, 2003a). A 2003 draft monitoring and assessment plan from RECOVER (*http://www.evergladesplan.org/pm/recover/aat.cfm*; accessed January 28, 2004) represents some progress in addressing these concerns.

Summary

Adaptive management in the Comprehensive Everglades Restoration Plan is currently more of a concept rather than a fully-executed management strategy. As outlined in the programmatic regulations governing the implementation of CERP, adaptive management is broadly defined. It is being applied to all aspects of performance, including progress toward achieving non-environmental outputs such as domestic water supply and maintenance of flood protection. The plan's ultimate restoration objectives are broadly and generally defined. To date, specific interim performance measures have not been developed, nor is it clear how the RECOVER teams will establish appropriate interim performance measures. The focus of the adaptive management effort is to relate outcomes and plan activities. There is, however, little explicit consideration of factors outside the plan (the external human and environmental drivers identified by CROGEE; NRC, 2003) that may influence ecological or other outcomes and that such factors must be considered within adaptive management. Some of these factors, such as prospective future changes in precipitation patterns, the direction and magnitude of which are not clearly understood, may be beyond the ability of managers to immediately prepare for. But other, more immediate factors such as population growth and associated increased water demands, are currently influencing outcomes and may be amenable to ameliorative actions.

An adaptive management approach in the Comprehensive Restoration Plan is an ambitious undertaking. Substantial investments in scientific activities have been made. However, reviews by the General Accounting Office and the National Research Council *Committee on Restoration of the Greater Everglades Ecosystem* emphasized that significant improvements in the monitoring program, including priority setting and development of more comprehensive indicators of outcomes, are still

required. This is essential because monitoring and ongoing assessment plays a central role not only in measuring outcomes, but also in refining attainable goals and modifying plans to achieve them. A review of the plan illustrates the remaining challenges in fully integrating modeling, monitoring, and research into a framework that emphasizes learning for refining models, and in developing institutional mechanisms to ensure that knowledge gained is effectively applied in adaptive management. The Comprehensive Restoration Plan is on the leading edge of the Corps' efforts to apply adaptive management in ecosystem restoration. These early evaluations of progress and shortcomings not only provide the opportunity for mid-course correction, but also serve as important lessons learned for adaptive ecosystem restoration in other parts of the nation.

MISSOURI RIVER DAM AND RESERVOIR SYSTEM

The Pick-Sloan Plan

The most important and lasting water development project on the Missouri River was the Pick-Sloan Plan. Passed as part of the 1944 Flood Control Act, the Pick-Sloan Plan represented a merger of plans prepared by the Corps and the U.S. Bureau of Reclamation. The Corps' plans focused on navigation enhancement and flood control through several dams on the Missouri's mainstem. The Corps' plans were being coordinated and promoted by the Corps' Missouri River Division Engineer, Colonel Lewis Pick. The Bureau's plans focused on irrigation and hydropower, and were developed in large part by the Bureau's regional director, Glenn Sloan. The Bureau's plans called for some ninety dams and reservoirs across the basin, along with hundreds of irrigation projects that would have doubled the basin's irrigated acreage (Carrels, 1999). Both plans were presented to Congress at a time when the creation of a basin-wide Missouri River authority was being considered. The proposal to create a basin-wide authority was decidedly unpopular with both the Corps and the Bureau, but there was pressure from President Franklin Roosevelt to create a single plan for basin development. To forestall the creation of a new basin-wide authority, Pick and Sloan and their respective agencies agreed to combine their plans. Congress approved the combined plan, directing the Corps to build the mainstem dams and the Bureau to provide water to irrigated agriculture. Prior to the passage of

the Pick-Sloan legislation, the Corps constructed one large dam on the Missouri River—Fort Peck Dam in Montana—which was built in the 1930s. Under Pick-Sloan, the Corps built five additional mainstem dams in the 1950s and 1960s. In addition to these six mainstem dams, the Bureau of Reclamation built Canyon Ferry Dam (also in Montana). There are today seven dams and reservoirs along the Missouri River (see Figure 4.2, in which the three largest reservoirs are labeled).

FIGURE 4.2 Missouri River Basin. SOURCE: Modified from NRC (2003).

Current Setting

The Missouri River dam and reservoir system supports a variety of uses, including recreation, fisheries, hydroelectric power generation, and flood control. The river also supports commercial navigation on a 735-mile stretch from the river's mouth at St. Louis upstream to Sioux City, Iowa. Water releases from the system's most downstream dam—Gavins Point—are scheduled to support a 9-foot navigation channel. Navigation is among the most controversial issues in current discussions of system operations. It was expected that the mainstem dams constructed as part of Pick-Sloan were going to generate substantial navigation benefits. But commercial traffic levels on the Missouri River have fallen well short of 1950 projections, peaking in 1977 at 3.3 million tons, with a fairly steady decline since then, to near 1.6 million tons in 1997 (USACE, 2000b). In comparison, barges on the Upper Mississippi carry more than 80 million tons per year (USACE, 2000b). Commercial navigation generated a modest (when compared with other benefits) level of $7 million of benefits in 1995 (USACE, 1998). Most of those navigation benefits are concentrated in the downstream sections of the navigable channel. The Corps maintains this 9-foot navigation channel pursuant to the 1945 Missouri River Bank Stabilization and Navigation Project. Since passage of this legislation, recreational use of the mainstem lakes has become much more important to upper basin economies. According to Corps data, recreation on the mainstem lakes increased from less than 5 million visitor hours in 1954 to more than 60 million visitor hours in fiscal year 2000 (USACE, 2000a). Annual recreational benefits for the region are estimated by the Corps at over $80 million annually (USACE, 1994).

Authorized purposes of the dams and reservoirs include flood damage reduction, water supply and irrigation, navigation, hydropower, fish and wildlife, and recreation. Some of the values of these authorized purposes have changed greatly since the Pick-Sloan era. The appropriate balance of these sometimes competing uses are central to the current decision making context for the Missouri River dams and reservoirs, and figure prominently in the Corps' ability to implement an adaptive management framework for the river and its basin. Management protocols for the Missouri River include many federal laws, one of which is the Endangered Species Act (ESA) of 1973. There have been significant post-settlement changes to riverine ecology: of 67 native fish species on the mainstem river, 51 are currently listed as rare, uncommon, or de-

creasing (NRC, 2002). One fish species (the pallid sturgeon) and two bird species (the least tern and the piping plover) are listed under the federal Endangered Species Act. In addition to these legal responsibilities, many stakeholder groups representing a wide and sometimes conflicting variety of preferences and values are intensely interested in management of the river. Interest groups that compete for Missouri River benefits include the basin states, navigation interests, environmental groups, floodplain farmers, river communities, and Native American tribes.

The Corps Master Manual

The six mainstem dams and reservoirs that the Corps operates on the Missouri River comprise the core of North America's largest reservoir storage system. The operations guidelines for this system are embodied in the Corps' Missouri River Master Water Control Manual, or "Master Manual," the first version of which was issued in 1960 by the Corps' Omaha office, which codified operations practices developed over the previous decades (Ferrell, 1996). The Master Manual does not define specific operating priorities for the system, but it does provide general guidance for addressing possible conflicts between uses. The Master Manual is supplemented by a more detailed Annual Operating Plan (AOP), which is also prepared by the Corps. In response to drought conditions across the Missouri River basin in the late 1980s, and because of strong differences of opinion on how the reservoirs should be operated, the Corps began revising the Master Manual. To date, the Corps has not yet produced a revised version of the Master Manual, a situation that reflects the complex and contentious political and legislative setting along the Missouri River.

Implementing Adaptive Management

The Corps has been involved with habitat restoration efforts on the Missouri since the mid-1970s. In cooperation with the U.S. Fish and Wildlife Service and with state conservation agencies, the Corps has implemented projects to mitigate the loss of natural resources resulting from bank stabilization and channelization of the river system. Formal authorization of the mitigation program dates to the 1986 Water Resources Development Act. The stated goal of the mitigation project was to restore five to ten percent of the habitat lost from the bank stabiliza-

tion and navigation project (Ferrell, 1996; USGS, 1997). Mitigation continues through experimental modifications of river structures, such as dikes, and enhancement of river flow through side channels and into backwater areas. Under the 1986 authorization, mitigation has been completed at nine sites, is underway at nine others, and nine additional sites have been targeted for acquisition (NRC, 2002). The emphasis in this mitigation project has been on terrestrial habitat, not on restoring pre-settlement ecosystem processes such as overbank flooding and cut-and-fill alleviation (see NRC, 2002, for more detailed advice on implementing adaptive management within Missouri River dam and reservoir system operations).

More substantial efforts at restoration that would adjust river flows to more closely mimic pre-settlement hydrologic patterns, however, have not received acceptance among all stakeholders, particularly among agricultural and navigation interests. In its Final Missouri River Biological Opinion issued in late 2000, the U.S. Fish and Wildlife Service (FWS) recommended an adaptive management program for managing river flows. The Fish and Wildlife Service recommended altering the current and steady year-round flows (approximately 32,000 cubic feet per second) to allow for more seasonal flows, a proposal that sparked intense debate, from hearings along the river to testimony presented to the U.S. Congress. Communities and some interest groups along the lower river, and elected officials from the State of Missouri, are concerned about potential impacts of high spring flows on agriculture and of low summer flows on navigation traffic. In contrast, upper basin state interests and their political leaders call for changes in order to avoid lowering upstream reservoirs in the summer that would harm the recreation industry there. Environmental groups call for restoration of some degree of seasonal flows that are fundamental to habitat restoration and to protecting endangered species.

The Corps released a draft Environmental Impact Statement (EIS) for revision of its Master Manual in August 2001. In that document, the Corps explained potentially useful efforts to move toward adaptive management of the Missouri River dam and reservoir system. Successful implementation of the concept, however, is constrained by the conflicts embodied within an array of federal laws, congressional authorizations, administration guidance, the Corps' own internal guidance, and differences of stakeholder opinion. Faced by the inconsistencies within this body of water policy, the Corps has been reluctant to depart from traditional authorizations (namely the 1945 Missouri River Bank Stabilization

and Navigation Project that authorizes a nine foot navigation channel), even when it has the legal authority to do so. As a result, the status quo remains in place and the impasse between conflicting objectives must be broken by Congress or by the courts.

The Corps has embraced the spirit of adaptive management in some of its recent Missouri River system planning documents. Conflicts and inconsistencies among statutory responsibilities, court orders, agency opinions, and stakeholder preferences continue to confound adaptive management actions on the Missouri River mainstem. A series of events as this report went to press illustrate these legal, political, and social entanglements. In July 2003, a federal district court ordered the Corps to temporarily lower Missouri River flows from mid-July to early September in order to comply with the Endangered Species Act. The flow reductions ordered were consistent with flow targets issued in a 2000 Biological Opinion from the U.S. Fish and Wildlife Service—from 25,000 cubic feet per second (cfs) at Gavins Point Dam to no more than 21,000 cfs until August 15, and to not more than 25,000 from August 15 to September 1. These flow reductions were relatively moderate in both duration and scale and posed relatively low risks for users along river (e.g., power plant cooling stations; drinking water supplies). They also offered an opportunity to examine ecosystem responses to changes in flow. Yet rather than reducing flows from Gavins Point Dam, the Corps opted to contest the court order. The Corps argued that the order was inconsistent with an earlier injunction issued by a different federal district court that ordered the Corps to operate the river in accordance with its Master Manual. The court found, however, that the Corps' refusal to lower the river as ordered was inconsistent with their obligations pursuant to the Endangered Species Act, and held that the Corps was in contempt of court. The Corps ultimately lowered flows consistent with the FWS flow targets—for three days at the end of the flow period suggested by the FWS. In December 2003, the U.S. Fish and Wildlife Service issued another Biological Opinion that maintained the Corps would violate the Endangered Species Act if the agency refused to lower summer water flows to benefit the endangered pallid sturgeon, and that a “spring rise” was not required because the Corps dam operations are not jeopardizing the least tern and the piping plover. Whatever the correct explanation for the events during the Summer of 2003, they at least forestalled an opportunity to apply adaptive management actions to managing the Missouri River Dam and Reservoir System and to restore some degree of presettlement processes.

Summary

Missouri River management is legally complex and highly politically charged, and efforts to adjust status quo operations are strongly contested. In this instance, reasons for the Corps' reluctance to lower river levels to uphold its obligations pursuant to the ESA might include a lack of support from the administration and the Congress to make such changes, political influence of influential constituents, or an inertia that favors traditional authorities over more contemporary statutes. Although detailed investigation of these issues was beyond the scope of this study, a previous National Research Council report considered these issues in some detail, and concluded that clarification from the U.S. Congress regarding Missouri River objectives was essential to better management: "Support of the U.S. Congress is ultimately needed to help establish goals for the use and management of the Missouri River system. Congress must also identify the necessary authorities to do so" (NRC, 2002).

The Corps has embraced the spirit of adaptive management in some of its recent guidance (e.g., its 2001 revised draft environmental impact statement; USACE, 2001b) for Missouri River management. Some elements of adaptive management do exist in the basin. For example, the Missouri River Basin Association (MRBA) has recently convened workshops that engaged basin stakeholders to discuss prospects for adaptive management, ecosystem monitoring, and more effective stakeholder participation on Missouri River management issues. The MRBA, which is a coalition of governor-appointed representatives from each of eight Missouri River Basin states (Iowa, Kansas, Missouri, Montana, Nebraska, North Dakota, South Dakota, and Wyoming) and the Executive Director of the Mni Sose Tribal Water Rights Coalition, has also been considering adaptive management efforts in other U.S. river systems, such as the Colorado River and the Upper Mississippi River, and how they might inform adaptive management for the Missouri. The U.S. Geological Survey sponsors the Columbia (MO) Environmental Research Center, which conducts research on large river floodplains and the effects of habitat alterations on aquatic and terrestrial ecosystems. State fish and wildlife agencies across the basin have also formed the Missouri River Natural Resources Committee, which aims to promote environmental stewardship based on ecological principles. A Missouri River Roundtable, with federal agencies as members, has also been created. Despite these and other positive developments across the basin, the Corps remains frustrated in its efforts to revise its Master Manual. As events in

the Summer of 2003 demonstrated, water management tensions in the Missouri are often resolved in courts. Support from the administration and Congress will be essential to creating an integrated and coherent adaptive management program for Missouri River management.

UPPER MISSISSIPPI RIVER

The Navigation System

The Upper Mississippi River begins at Lake Itasca, Minnesota, and ends at Cairo, Illinois, at the confluence of the Mississippi and the Ohio rivers (Figure 4.3). The Upper Mississippi River—Illinois Waterway (UMR-IWW) system also includes the Illinois River, which flows from near Chicago downstream to its confluence with the Mississippi at Grafton, Illinois. In the 1930 Rivers and Harbors Act, Congress authorized a 9-foot channel navigation project for the Upper Mississippi River. Pursuant to that act, the Corps constructed a series of locks and dams on the river. The dams created navigation pools that provided sufficient depth to support a 9-foot channel. There are today 29 locks and dams on the Upper Mississippi River, most of them constructed in the 1930s, and the Corps still maintains a 9-foot navigation channel. Commercial barge traffic carries grain (downstream), coal (upstream and downstream), and fertilizer and petroleum (upstream; NRC, 2001b), and several other products including scrap metal, sand and gravel, and vegetable products. The Upper Mississippi River supports many other uses, including the Upper Mississippi River National Wildlife and Fish Refuge (the longest such refuge in the United States), which supports a vibrant hunting, sport fishing, and boating enterprise.

Ecosystem Monitoring and Science

The Upper Mississippi River Environmental Management Program (EMP) was established as part of the Water Resources Development Act of 1986. The EMP originally had three components: 1) habitat rehabilitation and enhancement projects (HREPs), 2) Long Term Resource Monitoring Program (LTRMP), and 3) Computerized Inventory and Analysis (USACE, 1997). The Corps has overall management responsibility for the EMP. The LTRMP is today overseen by the U.S. Geologi-

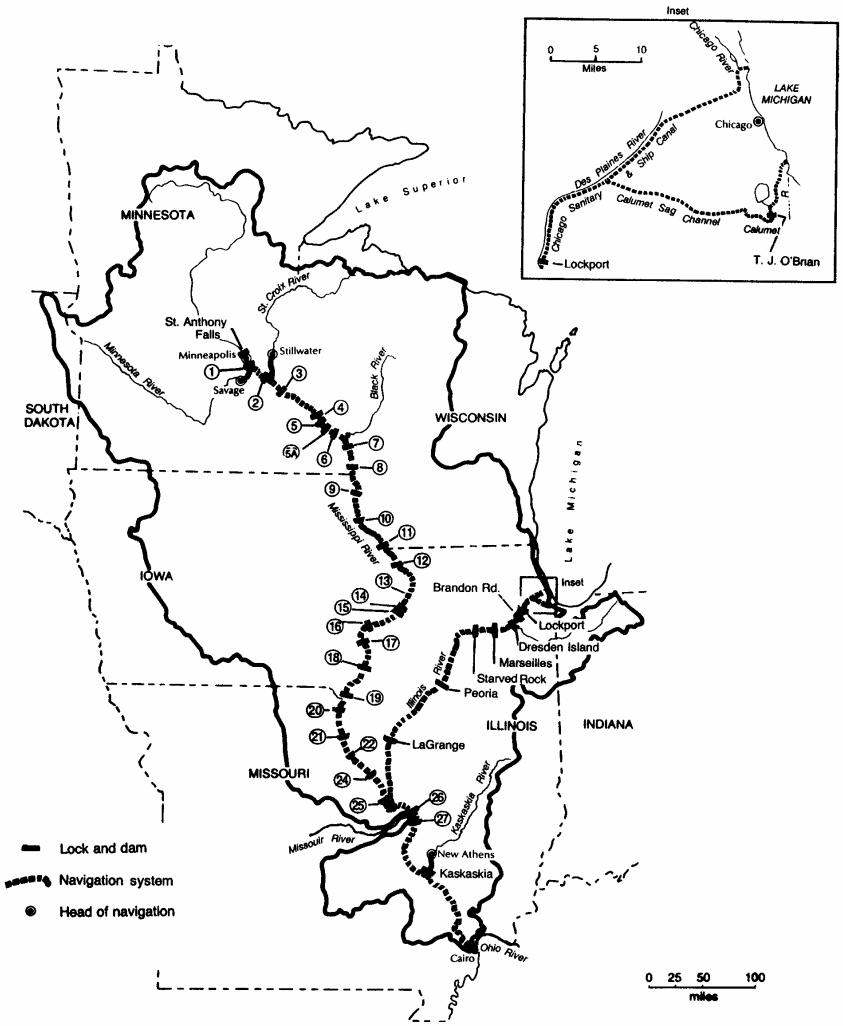

FIGURE 4.3 Locks and Dams on the Upper Mississippi River-Illinois Waterway System. SOURCE: USGS (1999).

cal Survey, in cooperation with the five Upper Mississippi River System states (Illinois, Iowa, Minnesota, Missouri, and Wisconsin). In 1999 the LTRMP became part of the Upper Midwest Environmental Science Center (UMESC) in La Crosse, Wisconsin. In a review of the EMP, the Corps stated that " . . . the EMP has come to be the single most important and successful program authorized by the Federal government for the purposes of understanding the ecology of the UMRS and sustaining its significant fish and other resources" (ibid.).

The LTRMP's primary mission is to analyze and report upon ecological conditions and trends of the Upper Mississippi River. The UMESC gathers ecological data through field, laboratory, and remote sensing methods, and the center has published hundreds of scientific and technical documents. In 1999 the UMESC issued a report that reviewed the ecological status and trends of the entire Upper Mississippi River system (USGS, 1999). The report represented a landmark of sorts, as it was the first time that the LTRMP data and historical observations were summarized in a single report. The report found that "Historical observations and research findings together make it clear that the reaches have been changed by human activity in ways that diminished their ecological health," but also concluded that "the ecological potential of the UMRS remains great" (USGS, 1999).

Although there is no congressional mandate to manage the Upper Mississippi River according to adaptive management principles, the Corps has been varying the heights of some Upper Mississippi's navigation pools in an effort to reintroduce a degree of natural variability to the ecosystem and thereby improve ecological conditions. The Corps began these efforts with several small-scale (on the order of a few inches of pool drawdown) efforts in 1996-1999. Drawdowns were conducted in Pool 8 (formed by Lock and Dam Number 8 at Genoa, Wisconsin) during 2000 and 2001. The fluctuations were relatively modest: in 2000, pool height was initially dropped six inches at the upper end, and in 2001 the height was dropped three inches. Some adaptive management elements were embodied in these actions, including citizen involvement (in establishing the magnitude of the drawdowns) and monitoring of the results of management actions. A review of these actions could yield insights into the responses of both ecosystems and human uses, and may thus hold lessons in the Corps' abilities and constraints in implementing adaptive management.

Outcomes

As one of the nation's large environmental monitoring programs that includes the Corps, it is important to ask how resources devoted to the EMP and LTRMP have proven informative and useful. Since the EMP's establishment in 1986, the most important management issue on the Upper Mississippi River has been the prospect of extending several locks (just north of St. Louis) in an effort to relieve occasional waterway traffic congestion. Formal investigations by the Corps into the economic justification for these extensions dates back to the late 1980s and continues today. Current plans call for a report with a final recommendation to be released in late 2004. During the course of the Corps' feasibility study, the U.S. Department of Defense requested the National Research Council to form a committee to investigate the economics and related analyses within the ongoing study. That committee's report stated:

> Although there has been some systematic research into the environmental effects of human and social activities on the Upper Mississippi River [the EMP] , the understanding of the complex ecosystem dynamics in the UMR-IWW system is limited in many areas . . . characterization of the current environmental system is insufficient, as it is in the early stages of scientific validation. Systemwide research should be conducted on the following topics: (1) cumulative effects of the existing navigation system on river ecology, (2) environmental effects of recent navigation system improvements, (3) cumulative effects of increased towboat passage, and (4) site-specific effects of future construction activities (NRC, 2001b).

The NRC report also concluded, "The EMP research effort should be enhanced to improve the assessment of the current navigation system's cumulative effects on the environment, and broadened to include studies of the impacts of barge traffic on river ecology." Despite possible past constraints on the EMP (which this panel did not investigate), the 1999 U.S. Geological Survey's "Status and Trends" report noted that sufficient data now have been collected so that the EMP could provide useful information for future river management decisions on the Upper Mississippi.

Summary

There is no federal legislation requiring adaptive management principles to be used in managing the Upper Mississippi River and its floodplain ecosystem. Nonetheless, some elements of an adaptive management program, such as the extensive ecosystem monitoring program managed by the Upper Midwest Environmental Sciences Center, are in place (although the monitoring program is not specifically designed to support adaptive management). The Corps, working in cooperation with the U.S. Department of the Interior, is also striving to introduce adaptive management concepts to management of the Upper Mississippi River ecosystem, and a recent Corps draft report demonstrates a good understanding of key concepts and implementation challenges (Lubinski and Barko, 2003). To its credit, the Corps and some of its fellow federal agencies, and some state resources management agencies, took the initiative to implement experimental drawdowns of navigation pools. Those drawdowns were heavily constrained, however, and thus of a small magnitude.

One observation is that the Corps will be unable to implement adaptive management principles unilaterally; cooperation from federal and state agencies and stakeholders will be required, especially in large ecosystems like the Upper Mississippi. The Upper Mississippi experience is important because it shows that formal management actions with river systems can be framed with stakeholder input and can improve scientific knowledge. The Upper Mississippi also shows the importance of the physical and social settings in which adaptive management is implemented. The Upper Mississippi River National Wildlife and Fish Refuge contains large expanses of publicly-owned backwater and floodplain areas, which allows the Corps some latitude in varying river flows and surface elevations. The drawdowns were implemented in a region where many inhabitants view the Mississippi River as a valuable ecological resource that supports important economic and leisure activities. Moreover, the Corps communicated closely with stakeholders before and during these drawdowns and has used stakeholder preferences to limit the extent of the drawdowns. This has led stakeholders to develop a degree of trust in the Corps and to a realization that adaptive management-type experiments can entail only limited impacts on activities such as boating. This trust could be important if a larger drawdown(s) is proposed in the future.

A fuller understanding of these positive and innovative efforts must be framed in terms of other adaptive management principles and the

condition of the Upper Mississippi River ecosystem. It is important to note that adaptive management entails not only *procedural* components, such as monitoring and adaptation, but also *substantive* dimensions. For example, a traditional tenet of adaptive management is the promotion of ecosystem *resilience*. In the 1978 landmark volume on adaptive management, C.S. Holling stated:

> The concept of resilience, in which the different distinct modes of behavior are maintained because of, rather than despite, variability, is suggested as an overall criterion for policy design. The more that variability in partially known systems is retained, the more likely it is that both the natural and management parts of the system will be responsive to the unexpected (Holling, 1978).

Resilience refers to an ecosystem's ability to recover from disturbances and to be self-sustaining without human intervention (Gunderson, 2000). The benefits of resilience are difficult to identify and estimate, however, which poses challenges to its implementation for a constructions and operations-oriented agency like the Corps. On the Upper Mississippi River, ecological conditions and trends suggest that ecological resilience has been compromised by the lock and dam and navigation pool system and that most key indicators suggest that conditions are not improving. For example, the 1999 USGS report noted the following in regard to floodplain forests:

> . . . the UMRS retains its ability to regenerate early successional forest communities only in the Unimpounded Reach, where water levels fluctuate. Forests in pooled reaches apparently are limited by water-level regulation for commercial navigation and show little ability to reset in response to disturbance. The navigation dams likely will limit the health and diversity of forests within the Impounded Reaches for the foreseeable future (USGS, 1999).

Despite the noted ecological importance of water level fluctuations, efforts at restoration along the Upper Mississippi have emphasized restoration of highly managed habitats, rather than the restoration of hydrologic and related geochemical and biological processes that contribute to ecological resilience.

The roles and influence of the administration and Congress on the

Upper Mississippi are of great importance. In the 1986 Water Resources Development Act (WRDA 1986), the Upper Mississippi River Management Act stated that the river was to be recognized as "a nationally significant ecosystem and a nationally significant commercial navigation system" (P.L. 99-662). Despite this stated importance of ecological well-being, maintenance of the nine-foot navigation channel remains the prevailing authorization on the Upper Mississippi River. As pointed out in the 1999 U.S. Geological Survey report, the navigation pools and reduced variability in Mississippi River flows and river levels have negatively impacted river ecology: "Historical observations and research findings together make it clear that the reaches have been changed by human activity in ways that diminished their ecological health" (USGS, 1999). The WRDA 1986 legislation does not provide clear guidance to the Corps on how to appropriately balance traditional economic values (navigation) and environmental values. Lacking clear direction on how to appropriately balance these values, the Corps abides by the congressional mandate to provide a minimum nine-foot channel, and implements environmental restoration and protection programs such that this channel depth is not compromised. Environmental groups are generally dissatisfied with this operational regime, claiming that the balance called for in the WRDA 1986 has " . . . never been reflected in national policy . . . " and that " . . . some balance between these competing needs must be sought" (League, 2003). The 1930 channel authorization does not require strict and permanent maintenance of a 9-foot channel, however, and the exploration of alternative operational regimes would allow the Corps more flexibility to implement adaptive management actions and increase ecosystem resilience. At the same time, some stakeholder groups and some citizens have demonstrated a reluctance to allow the Corps to enact substantial navigation pool drawdowns. Adaptive management could provide a framework for stakeholders and the Corps and other federal agencies to explore the relations and trade-offs between Upper Mississippi River ecology, navigation, recreation, and other uses in a more systematic fashion.

COASTAL LOUISIANA

Multiple Corps Responsibilities

For over a century the Corps has played a large role in coastal Louisiana through its flood control and navigation mission relative to the

Lower Mississippi River. The establishment of a system of levees along the lower river in the 1930s to both prevent flooding of adjacent lands and to confine to the river to its channel and thus enhance navigation, was consistent with a mandate to protect citizens and infrastructure from flooding and to facilitate economic development. The impact of these measures in isolating the Mississippi River Deltaic Plain from the river, and thus its sustaining source of freshwater and sediments, were unappreciated at the time. In the aftermath of the historic 1927 flood, the Corps was also directed to regulate the river flow from the Mississippi and Red rivers down the Atchafalaya River to the Gulf of Mexico and to construct and manage spillways to alleviate the risk of overtopping of levees. In the later half of the twentieth century, the federal interest was expanded to include a number of relatively deep navigation channels, such as the Mississippi River-Gulf Outlet and Calcasieu Ship Channel, connecting inland ports and waterways with the Gulf of Mexico. These channels caused salt water to intrude into previously freshwater bays, bayous, and wetlands. The network of flood protection levees was also extended to afford communities protection from storm surges and backwater flooding. The Corps regulatory programs also played a role in the dramatic environmental changes in coastal Louisiana, permitting extensive channelization of coastal wetlands mainly related to oil and gas exploration, development, and transportation.

Wetland Loss

As a result of the cumulative effects of these and other alterations of the coastal landscape, and the disruption of the processes that created and sustain the delta and adjacent coastal environments and natural processes, the marshes, swamps, bays and barrier islands that comprise coastal Louisiana experienced dramatic changes during the latter half of the twentieth century. The rate of net loss of Louisiana's coastal wetlands has been estimated at 25 to 35 square miles per year during various segments of this half-century (Louisiana DNR, 1999), posing threats to the productivity and biological resources of the coastal ecosystems, the safety of residents, and the infrastructure supporting this population and important industries such as oil and gas production.

The causes of rapid wetland loss and change in the characteristics of associated estuarine environments are multiple and complexly interrelated. The changes accompanied and followed pervasive physical and

hydrological alteration of the estuarine-wetland complex itself at a number of scales. The large-scale navigation channels mentioned above facilitated more extensive and vigorous tidal exchange and interconnection of previously isolated hydrological basins. Extensive canals were dredged through the wetlands to afford access to oil and gas exploration and production sites and corridors for transportation of product via pipelines. In addition to the direct losses of wetland due to dredging, the material removed was typically side cast as spoil banks that interrupt the natural inundation and drainage of the wetlands. Still other wetlands were affected by impoundments associated with failed agricultural conversion or with water-level management to provide waterfowl habitat. The net direct and indirect consequences of these physical and hydrological alterations were greater intrusion of tides, storm surges, salinity, and impoundment of water on wetland surfaces that causes mortality or prevents recruitment of emergent plants.

The human-induced changes that began even earlier (i.e. closure of distributaries along the lower river such as Bayou Lafourche and the prevention of flood-induced crevasses and seasonal overbank flooding) led to a longer-term problem for the Deltaic Plain wetlands. The periodic supply of sediments, fresh water, and nutrients from the Mississippi River has historically built and sustained the wetlands in the face of very high rates of relative sea-level rise due to subsidence of the thick layer of Holocene sediments on which the wetlands sit. In addition, it now appears that withdrawals of oil, gas, and associated formation waters during the last half of the twentieth century caused accelerated subsidence in some regions of the coastal zone. The only portions of the Louisiana coastal zone that have had only minor losses of wetlands or that have actually gained wetlands are adjacent to the mouth of the Atchafalaya River, which receives thirty percent of the combined flow of the Mississippi-Red river system. These wetlands have received the fluvial subsidies that have been interrupted elsewhere. Scientific consensus suggests that whatever the cause, channelization of wetlands, subsidence, or even accelerated sea-level rise due to global warming, reconnection to the fluvial supply of sediments and other materials that build and sustain the coastal wetlands must be the foundation for maintaining and restoring coastal Louisiana's ecosystems (Boesch et al., 1994).

Role of the Corps in Wetland Restoration

In recent decades, the Corps has been the lead agency in efforts to address some of the effects of these actions through projects justified on the basis of their net economic development benefits, rather than for ecosystem restoration. These include the placement of materials dredged from river channels to create or protect wetlands and controlled diversions of Mississippi River waters into adjacent estuaries and wetland at Caernarvon and Davis Pond, the former into the Breton Sound Basin and the latter into the Barataria Basin (Figure 4.4). The latter projects aim to restore salinity gradients to benefit economically important estuarine oyster habitat.

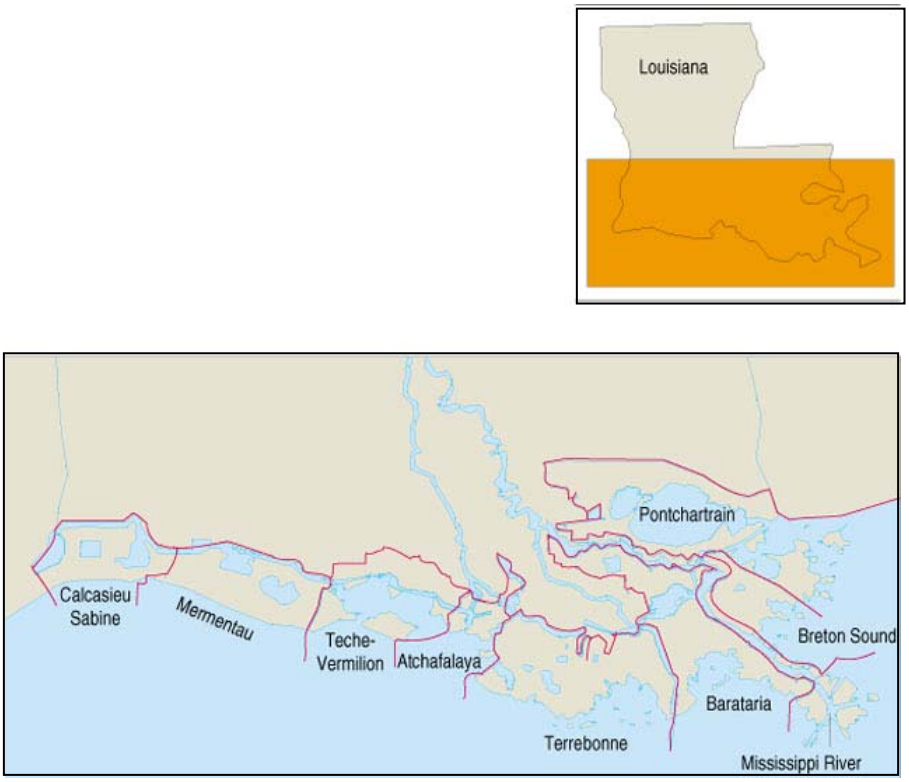

FIGURE 4.4 Louisiana Coastal Wetlands. SOURCE: Johnston, et al. (1995).

The role of the Corps of Engineers in the restoration of coastal Louisiana ecosystems expanded significantly with passage of the Coastal Wetlands Planning, Protection and Restoration Act of 1990 (CWPPRA, PL-101-464). Although this act is national in scope, it established a priority for Louisiana wetland restoration projects. CWPPRA provides a dedicated federal revenue stream of approximately $35 million per year for restoration projects selected and managed by a federal-state Task Force (the Corps receives the appropriations and chairs the Task Force). To date, there have been 141 different CWPPRA projects across coastal Louisiana (USGS, 2003), most of which have been demonstrations or relatively small projects involving shoreline protection, hydrological restoration, or wetland creation.

The federal agencies represented on the CWPPRA Task Force and the State of Louisiana realized, however, that although the CWPPRA projects have been increasingly integrated within the hydrological basins along the coast, the approach was still piecemeal and inadequate in scale to significantly reduce, much less, reverse the rate of wetland loss across the state. The funding level for CWPPRA did not allow consideration of the large and expensive diversions of river water into the surrounding wetlands that experts thought would be needed to effectively address the problem. The Task Force and the state produced a much more comprehensive and ambitious strategy, *Coast 2050: Toward a Sustainable Coastal Louisiana (*Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998; *http://www.mvn.usace.army.mil/prj/lca/;* accessed May 4, 2004), which included more than 80 projects and actions to achieve objectives for each of the hydrological basins along the coast.

The feasibility and benefits of many of the approaches included in the 2050 Plan are highly speculative. Consequently, the Corps of Engineers, with co-sponsorship by the State of Louisiana, is currently undertaking the Louisiana Comprehensive Coastwide Ecosystem Restoration Feasibility Study, or LCA Study for short. The LCA study builds on the 2050 Plan, but seeks to provide more rigorous analysis of design alternatives, benefits and costs within each of three subprovinces along the coast (Figure 4.4). Led by the New Orleans District office, the Corps is preparing a report to Congress that will seek authorization under the Water Resources Development Act for a comprehensive program to address wetland loss in coastal Louisiana. The authority would be for an umbrella program, much like the Comprehensive Everglades Restoration Project, under which specific projects would be subsequently authorized and funded.

Summary

Various forms of adaptive management have been employed in several previous projects implemented by the Corps for economic development, for CWPPRA projects, and in the development of the Louisiana Comprehensive Coastwide Ecosystem Restoration report. River diversions at Caernarvon and Davis Pond have been monitored to determine the effects on salinity distribution and to address concerns about the introduction of harmful substances or other undesirable effects. Although not specifically designed to support adaptive management, interpretations of the monitoring data at Caernarvon (Lane et al., 1999) have contributed to quantifying nutrient removal and wetland growth rates in ways useful to the design of future diversions and the operational regimen for this diversion. For example, analysis of results from the estuaries and wetlands receiving the Caenarvon diversion have led to the realization that significant restoration benefits could be achieved through pulsed releases lasting several weeks while avoiding undesired salinity lowering on oyster grounds lower in the estuary. This is now being tested by more closely monitoring experimental releases within an adaptive management framework.

The LCA Study is explicitly applying adaptive management, within the Corps' existing authorities, as a means of refining the design and operation of specific projects and learning by doing within the envisioned umbrella program that will extend over several decades. An adaptive management approach is particularly suited to the emerging strategy because of the multiple, but similar, water diversion and control components that are being considered, and because of the uncertainties involved not only in project performance, but in other important variables (e.g., variations in river flow, impacts of hurricanes, etc.).

GLEN CANYON DAM AND THE COLORADO RIVER ECOSYSTEM

One of the notable and sustained adaptive management efforts in the United States is the Glen Canyon Adaptive Management Program (AMP). Founded in 1995 to help meet the monitoring requirements established in the 1992 Grand Canyon Protection Act, the AMP is building upon the extensive scientific program of the former Glen Canyon Environmental Studies (or GCES, which was conducted in two phases, 1982-

1988 and 1988-1996). The Adaptive Management Program is focused on the Colorado River ecosystem in the Grand Canyon (Figure 4.5). The Secretary of the Interior's designee administers the AMP. The Grand Canyon Protection Act of 1992 mandates operation of the dam to ". . . protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established." An Environmental Impact Statement (U.S. Bureau of Reclamation, 1995), conducted in response to concerns over the downstream effects of the operations of Glen Canyon Dam, established the AMP to provide advice to the U.S. Secretary of the Interior on a continuing basis.

An Adaptive Management Work Group (AMWG) includes representatives of roughly two dozen groups with interests in the Grand Canyon and in Glen Canyon Dam operations (these groups include federal and state agencies, environmental groups, Indian tribes, and power and recreation interests). A Technical Work Group (TWG), composed mainly of representatives of the AMWG stakeholders, advises the AMWG on scientific and technical matters. The program also features a science center, composed of full-time staff, known as the Grand Canyon Monitoring and Research Center (GCMRC) in Flagstaff, AZ. The center is responsible for monitoring Colorado River ecology to help improve understanding of the downstream effects of Glen Canyon Dam operations. And, according to the 1995 environmental impact statement that described the structure and operations of the AMP, it is also to include an independent review panel(s) (U.S. Bureau of Reclamation, 1995). Although the Corps of Engineers is not a participant in the Adaptive Management Program, the preeminence and lengthy experience with adaptive management in the Grand Canyon should be of interest and value to the Corps.

The AMP is based on recognition that operations of Glen Canyon Dam have significantly altered downstream ecology of the Colorado River in the Grand Canyon. Section 1802 (a) of the AMP has implemented some adaptive management program components to good effect. The Grand Canyon Monitoring and Research Center has taken the lead in informing stakeholders about the goals of and uncertainty involved with adaptive management. Through activities ranging from meetings to rafting trips, stakeholders have developed informal relations and lines of

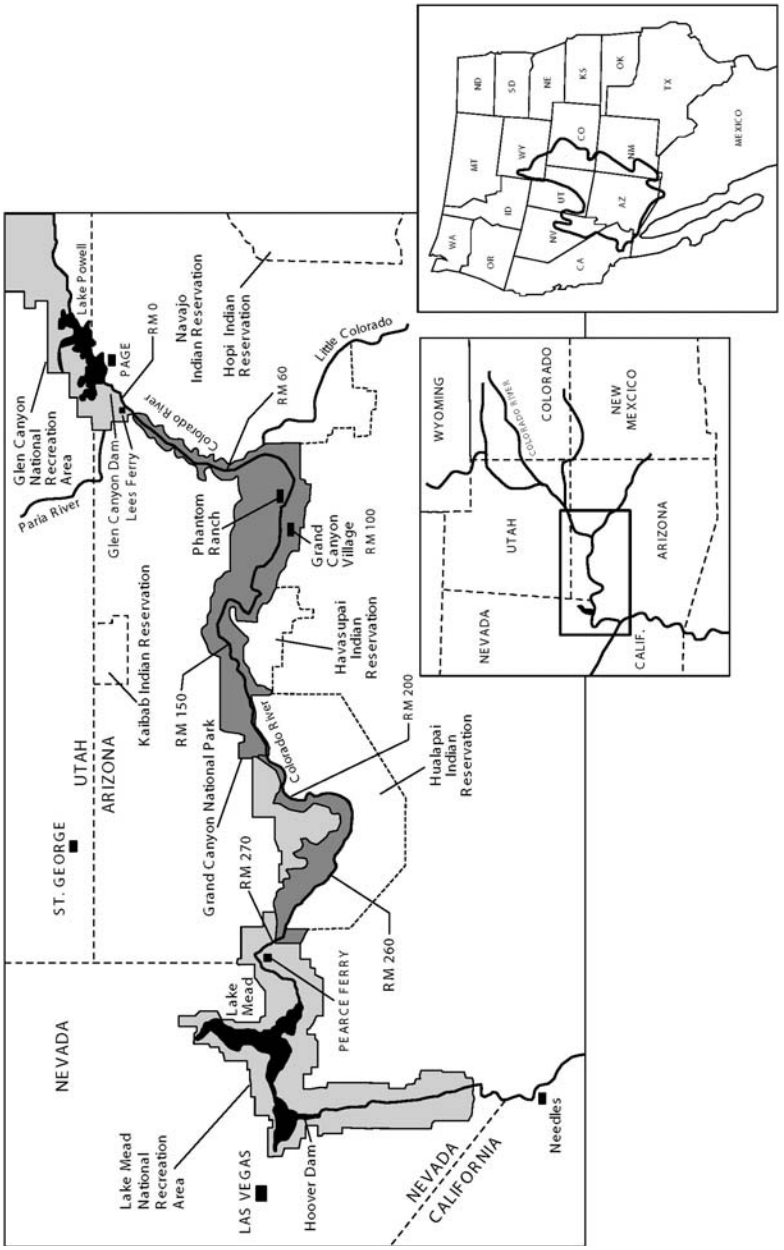

FIGURE 4.5 Grand Canyon River Ecosystem and Colorado River Basin (Inset). SOURCE: U.S. Bureau of Reclamation (1995).

communication. Experimental flows have been conducted, the most notable being a controlled flood in March 1996 when high water flows were released from the dam to simulate the spring rise that, in pre-dam conditions, transported sediment and helped restore beach habitat. Another experiment in the summer of 2000 involved low water flows in an effort to enhance conditions for native fish species. These experiments were extensively monitored and the results used in subsequent deliberations about dam operations.

The AMP is, however, struggling with the constraints inherent to most adaptive management efforts. Different values and priorities among stakeholders have stymied the creation of a set of clearly stated management objectives. As noted in a 1999 National Research Council report, the AMP has "not produced a scientific and stakeholder-based consensus regarding the desired state of the ecosystem." Further, the range of possible experimental actions is limited by political and economic conditions. For instance, some recommended experiments in 2001 were postponed because of increased energy demand on the West Coast. Finally, and importantly, the independent review component of the program has never been fully and formally implemented. Lessons from the Adaptive Management Program that may be useful for the Corps include: the value of a congressional act in keeping focused on ecosystem recovery, the difficulties in forging consensus among stakeholders, the uncertainties and disagreements associated with some ecosystem monitoring results, the limitations of science to help establish management actions, and the potential value of (as well as some resistance to) independent review in addressing controversial or sophisticated issues.

COMMENTARY

The Corps has implemented some adaptive management principles and programs, with degrees of support from the U.S. Congress ranging from no specifically authorized capacity, to resources for monitoring and science programs, all the way to explicit authorization of adaptive management in the Florida Everglades. A review of the case studies presented in this chapter yields several observations and some commonalities.

Adaptive management is often implemented in river and aquatic ecosystems that are experiencing ecological decline, sharp differences of opinion among stakeholder groups, and an inability to make significant

departures from the status quo. Many parties, however, view the concept with skepticism; defenders of the status quo naturally resist new management directions, managers may interpret its implementation as indicating failure of their past decisions, some may view it as a vehicle to help circumvent environmental and other standards or for taking only minimal actions, and budgeteers may be concerned that it implies a blank check for an endless stream of monitoring and science-based programs. Whatever perspectives are held, successful implementation of adaptive management will require sustained participation. In addition to these barriers, actions taken under an adaptive management framework may not yield an abundance of positive and clearly understood results.

Paradoxically, however, these conditions may actually enhance the chances of the usefulness and success of adaptive management. Legislators should recognize that declining ecological conditions must eventually be addressed in order to conform with environmental statutes such as the Endangered Species Act. Stakeholders who wish to see management changes may welcome the prospects presented by adaptive management. In any event, the settings of declining environmental quality and political gridlock have often resulted from conflicts that have obstructed efforts to employ adaptive management-like principles and to adjust to emerging realities of shifting and broadening social preferences.

Decisive management actions and ecological recovery have, for the most part, not been realized, but given that it has often taken decades to arrive at the current situation, the way forward will require patience (whether adaptive management is used or not). Increased social preferences and attendant legislation aimed toward restoration of some degree of natural ecological processes and sustainability offer opportunities for adaptive management actions. Initiating communications among stakeholders is of great importance to the Corps and to the adaptive management process. The backing of the administration and the Congress, in terms of resources, as well as legislative authority, is crucial in encouraging sustained stakeholder participation in such efforts. In the Missouri, Congress has not established a formal adaptive management stakeholder group or larger program, or a formal basin-wide science program. By contrast, support from the administration and the Congress has been instrumental to the significant adaptive management programs in the Everglades and the Grand Canyon. Federal resources have been important to improving knowledge of ecological conditions in the Everglades, the Grand Canyon, the Louisiana Coastal Area, and within the Upper Mississippi River's Environmental Management Program. Sustained support

from Congress for monitoring on the Upper Mississippi has helped synthesize and improve scientific knowledge of the Upper Mississippi River system. Congressional legislation mandating the Everglades restoration effort, establishing the Coastal Wetlands Planning, Protection and Restoration Act, and creating a Grand Canyon Protection Act have legitimated efforts toward improving ecological conditions. Beyond the provision of resources, the administration and the Congress should help provide clearer direction to the Corps when the agency is obliged to respect legislation and administration guidance that reflects internal inconsistencies.

5

Prospects for Adaptive Management in the Corps

This chapter identifies changes to Corps operating policies, programs, and organizational structure that could be useful in promoting adaptive management practices within the agency and within its existing and future water projects. As discussed, some of these changes can be initiated and promoted by the Corps, but others will require direction and guidance from the Congress, and the assistance and support of the administration, the Congress, and the states.

COMPONENTS OF ADAPTIVE MANAGEMENT

Evaluations and Operations

The Corps' civil works program for water resources traditionally focused on constructing new projects. But because of declining budgets for federal water development, declining public support, and a decreasing number of favorable project sites, this traditional focus is in a state of flux. This changing context suggests that in the future, operations and maintenance of existing infrastructure will become an increasingly important part of the Corps work program. Identifying operation schemes that meet today's needs and preferences and that can be adjusted to changing conditions will require monitoring of project impacts, flexibility to make operational changes, and close cooperation with other agencies and with the public. As discussed in Chapter 2 and elsewhere in this report, monitoring and evaluation of project outcomes are core adaptive management principles. These post-construction assessments could include the monitoring of ecological, economic, or other relevant variables, as well as broader evaluations of project or program effectiveness. **Post-construction evaluations should be a standard for the adaptive management of Corps projects and systems (Recommendation 1).**

Stakeholder Collaboration

The Corps continues to gain experience with the concept and practice of adaptive management, and in some places—such as the Upper Mississippi—the agency's responsiveness to stakeholder input may be enhancing public trust in the agency. There is much to be learned about how to successfully incorporate the concept, and the Corps should continue to move forward in its collaborative efforts. The agency could, for example, publicize examples where stakeholder-driven adaptive management actions led to beneficial effects that were largely unanticipated, and seek to learn from past experiences throughout the agency. Stakeholder and agency involvement should begin at the start of adaptive management programs and should include stakeholder participation in periodic review of monitoring results and management models. The Corps' experiences with Shared Vision Modeling, which involves stakeholders in assessing possible outcomes through models of assumptions and key processes, provide similar examples of useful approaches.

Resources and related support from the administration and Congress have been fundamental to establishing adaptive management programs in Florida's Everglades and in the Colorado River below Glen Canyon Dam. This type of support from the administration and the Congress has also been essential in promoting ecosystem monitoring and inter-agency collaboration on the Upper Mississippi River. A lack of this type of support for broad, meaningful stakeholder participation may be contributing to decision making gridlock on the Missouri River. The administration and the Congress should ensure that adequate resources are provided to promote sustained, meaningful stakeholder collaboration within adaptive management initiatives. **Stakeholder collaboration should be an integral component in the adaptive management of Corps projects and systems (Recommendation 2).**

Independent Expert Review

In addition to differences of opinion among stakeholders, the complexities of ecosystems may yield variations in scientific results and differences of scientific opinion. Ecosystem monitoring programs and physical, biological, and economic models do not always yield results that are interpreted the same way by all scientists and other interested parties. Such ambiguities can hinder adaptive management's cycle of actions, observations, evaluations, learning, and new actions. Moreover,

as recent critiques of the adequacy of the science programs supporting adaptive management in the Comprehensive Everglades Restoration Plan illustrate, independent review can point out inadequacies in modeling, monitoring, and assessment that may result from inertia or inadequate interagency coordination. Although such independent advice is useful and increasingly common in some circles, the use of experts will not eliminate the uncertainties that are endemic to most management decisions. Agencies and decision makers will often have to use their best judgment in adaptive management programs; however, independent experts can validate the assumptions and reasoning involved. **Independent experts should be periodically enlisted to provide advice on Corps adaptive management initiatives (Recommendation 3).**

A CENTER FOR ADAPTIVE MANAGEMENT

Sound U.S. water resources management in the future will generally require organizations with a broader mix of disciplinary expertise than was employed in twentieth century water resources decision making. Demands for traditional Corps programs in navigation, flood risk management, and coastal protection will continue. Much of the infrastructure to serve these needs has been constructed, and the construction of large amounts of new infrastructure does not appear likely because of, among other reasons, declining civil works appropriations (USACE, 2001). If the Corps is to make a successful transition to focusing on better management of existing infrastructure, it will need to effectively integrate environmental, social, and economic considerations and changes into operational decisions.

Engineers and engineering concepts will be important in supporting management policies and actions; but the Corps' future engineering needs will continue to broaden to encompass fields such as systems analysis, operations research, environmental engineering, and decision support systems. Previous studies of the Corps of Engineers (e.g., NRC, 1999b), reviews of other U.S. water management organizations (Jacobs and Wescoat, 2002), and assessments of water management organizations in the developing nations (Scudder, 1994) all suggest that better integration of economic and environmental considerations into water resources projects requires adequate staff expertise in environmental and social sciences. Not only should the Corps ensure that is has access to this type of expertise in order to implement adaptive management, but these experts should be meaningfully included at all stages of project

management and planning. If adaptive management concepts and practices are to be consistently and comprehensively implemented through the Corps, and if adaptive management programs are to continually improve, the Corps must have a nucleus of interdisciplinary expertise to track lessons within the agency, stay abreast with current practices, and enhance the flow of knowledge within the agency and between the Corps and external experts. This is not to suggest that the Corps lacks knowledge of adaptive management and must recruit new staff members. Many Corps staff members are familiar with adaptive management techniques and many staff members have experience in working with the concept in settings like the Florida Everglades. The issue is that agency-wide guidance for adaptive management (such as a "best practices" guide) has not been developed, lessons from Corps district and division offices are not being meaningfully shared among these offices and through the agency, and staff are not specifically tasked to follow developments in the professional literature or adaptive management experiences in the United States and around the world. These organizational components and documents are essential if adaptive management is to be effectively implemented within the Corps. If adaptive management concepts are to be adequately developed and promoted, the Corps will need to have a cadre of staff dedicated to these tasks on a full-time basis. The Corps of Engineers will also need a stronger and more focused effort in staying abreast of conceptual developments in the professional scientific literature, and in tracking experiences across the United States, around the world, and within the Corps. If more attention and resources are not devoted to a more systematic process for implementing adaptive management through the agency, information essential for useful adaptive management applications will not be systematically gathered, analyzed, and applied.

One alternative for ensuring more systematic progress with adaptive management would be to establish interdisciplinary adaptive management teams within each Corps District office. A limitation of this option is that it is not yet known how many staff, and what types of expertise, can most effectively implement and sustain adaptive management practices through the Corps. This option thus poses the possibility of devoting too many staff (in a period of tight budgets) to adaptive management efforts. In addition, the resources required for this effort are likely beyond current budgetary limits. Another option would be to assemble a team of experts from outside the Corps to convene adaptive management workshops at Division and District offices. This would not require the hiring of new staff, and the expert team could be quickly assembled and

the workshops convened in a relatively short time period. Although such workshops could complement the development of adaptive management within the Corps, they would not ensure sustained, long-term progress within the agency—which is essential if adaptive management is to be useful to the Corps. External experts may also have limited knowledge of Corps planning guidance and project operations, which may limit the effectiveness of advice provided in a short-term, workshop setting.

Yet another alternative would be to establish a Center for Adaptive Management within the Corps. The Center would be a small, interdisciplinary group with expertise in adaptive management principles and applications. It should work with Corps district or division offices in helping understand ways in which adaptive management concepts and actions can be implemented. It would not itself implement adaptive management of specific projects, but rather would assist Corps district-level staff in the design, implementation, and review of adaptively-managed projects and programs. Examples of specific tasks for the Center might include:

- develop agency-wide guidance on adaptive management approaches and best practices;
- supply training, facilitation, and assistance to district planners and managers in developing adaptive management schemes and monitoring designs;
- evaluate progress, limitations, and successes of adaptive management programs, such as those in the Everglades, the Missouri River, and coastal Louisiana, with the objective of improving approaches and outcomes;
- facilitate sharing of information concerning adaptive management throughout the agency. The Center should also seek to develop collaborative relations with agencies beyond the Corps working with adaptive management (e.g., U.S. Department of the Interior), and ;
- review outcomes of stakeholder participation in adaptive management.

Potential drawbacks to concentrating expertise within a center exist, such as a possible over-reliance on the center to implement adaptive management, or a lack of familiarity within the center of local conditions important to adaptive management efforts. The Corps could, however, employ a modest amount of resources to considerable benefit by employing adaptive management concepts and experience consistently through-

out the organization. Based on the foregoing considerations, this third alternative is the preferred choice.

Congress should establish a Corps of Engineers Center for Adaptive Management (Recommendation 4). The Center should be initially established for a relatively short (e.g., five years) term, with its progress and effectiveness periodically evaluated. Periodic review and evaluation can be especially important in helping better understand the level of resources and staff necessary to promote useful adaptive management applications through the agency. The Center for Adaptive Management should be operated and funded according to adaptive management principles: it should start as a modest and carefully planned effort that should be periodically evaluated and adjusted accordingly.

ROLES OF THE ADMINISTRATION AND CONGRESS

Legislation and Priorities

As illustrated in this report's case studies, the Corps often operates in contexts of internally-inconsistent legislation and operating authorities, or without a clear process for re-setting management objectives and priorities. As new laws and authorizations have been added to the Corps' list of responsibilities over the years, the degree to which new obligations are consistent with pre-existing obligations has not been carefully evaluated, nor have existing objectives been revisited and adjusted accordingly. This has resulted in some situations in which existing project authorizations are not fully consistent with new project authorizations. For example, 1930 and 1945 authorizations to provide nine-foot navigation channels on the Mississippi and Missouri Rivers, respectively, have not been adjusted to incorporate subsequent authorized purposes and shifting social preferences and priorities.

The accretion of potentially inconsistent authorizations and legislation can contribute to the management gridlock that characterizes many U.S. river systems (some of the gridlock can also be attributed to conflicting stakeholder goals and preferences). These impasses must be broken either by Congress or by the courts. In August 2003, for example, a federal district court in Minnesota resolved this type of legal ambiguity on the Missouri River, affirming a July 2003 injunction that ordered the Corps to reduce summer flows on the Missouri River in order to comply with the Endangered Species Act. Situations in which the limits of the Corps' obligations and authorities are not clear can hinder the

agency's adaptive management efforts. A clearer sense of water policy priorities from the administration and Congress would provide the Corps a better sense of limits and priorities within its adaptive management efforts. A line agency like the Corps of Engineers cannot legitimately resolve such conflicts; but because the Corps often finds itself in the midst of such conflicts, its attention to and resources for other, more appropriate actions (such as adaptive management) are diverted. **The administration and the Congress should help resolve conflicts and inconsistencies within the body of national water policies, and should clarify water management objectives that it wishes the Corps to pursue (Recommendation 5).**

Continuing Authorities

Legal authorities that govern Corps project operations present barriers to the agency's move toward adaptive management. The Corps is currently tasked to construct projects that are often tailored to the interests of a local project sponsor. Post-construction operations of Corps projects are often turned over to a non-federal sponsor. Adaptive management will entail a broadening operational and management emphasis within the Corps. New Corps projects will continue to be constructed, but adaptive management will require a stronger emphasis on post-construction monitoring, evaluation, stakeholder participation, and operational adjustments and changes. Examples of "continuing authorities" that allow the Corps to review and modify project operations without seeking additional congressional authorization include the authorization for the Comprehensive Everglades Restoration Program, a "Section 1135" authority from the 1986 Water Resources Development Act, and a "Section 216" authority from the 1970 Flood Control Act.

These existing authorities, however, were not explicitly designed to promote adaptive management principles and ongoing, iterative processes of monitoring, evaluation, and operational adjustments. If adaptive management is to be meaningfully implemented within the Corps, a stronger and more explicit continuing authority(s) will help reorient the agency from a traditional emphasis on project construction, to a broader program that includes post-construction monitoring, stakeholder participation, and operational adjustments. Thorough and comprehensive (environmental, economic, and social) evaluation of post-construction outcomes is essential to ensuring efficient project operations. Existing current authorities do allow for some degree of this; but they lack specificity

and they were primarily enacted before the Corps began implementing adaptive management principles. A new continuing authority for the Corps should emphasize the importance of the type of adaptive management principles discussed in this study (see Chapter 2).

Congress should provide a new study authority and direction that will increase the Corps' ability to monitor and evaluate post-construction changes and periodically adjust operations of existing projects in order to increase overall project benefits (Recommendation 6). The new authorization should require periodic appraisal of project effectiveness and operational modifications. Congress should also appropriate sufficient funding (with appropriate cost sharing by co-sponsors) for post-construction monitoring and evaluation of environmental and economic objectives and subsequent outcomes. These recommendations do not assume any change in the present division of responsibilities regarding operation and maintenance. They do assume stakeholder participation in post-construction adaptive management activities (see also the report from the 216 Study coordinating committee for additional details regarding a new Corps of Engineers study authority).

Resources for Adaptive Management

Funding of Corps of Engineers projects is governed by cost-sharing formulae that typically require resources from a local sponsor; these local sponsors are often—and understandably—reluctant to support studies and operations that do not address their specific needs. The cost-sharing nature of Corps projects, however, may inhibit adaptive management practices, as sponsors for adaptive management programs (vs. specific projects) may be difficult to identify. Although cost-sharing arrangements offer some advantages, successful implementation of adaptive management in the Corps may require adjustments to the cost-shared nature of Corps projects. Current policy guidance and budgeting procedures also inhibit adaptive management practices. In addition, most projects require a local sponsor to share in the initial costs of the project and in most cases assume full responsibility of post implementation costs.

Adaptive management represents a process that is qualitatively different than traditional civil works construction, and in some ways represents a paradigm shift for the Corps, as well the administration and Congress. Adaptive management will entail changes in operational styles, organizational accountability, and appropriations. Implementation of

adaptive management for existing projects does not represent a traditional Corps of Engineers "project." Furthermore, even though some components of adaptive management will entail new costs, adaptive management efforts should also seek to build upon previous and existing investments. Adaptive management will also often entail benefits that extend (spatially) beyond a local water project, which runs counter to the current process in which the Corps works closely with a specific cost-sharing local sponsor. In addition, under current authorization-appropriation procedures, federal funds are allocated to the Corps primarily on a project-by-project basis. The process of appropriating federal funds to the Corps of Engineers may thus need to be revisited if adaptive management is to be efficiently implemented and sustained. The administration and the Congress should thus consider developing new cost sharing formulas in order to effectively apply adaptive management principles to new and existing projects.

In addition to the willingness of the Corps, cooperation from other arms of the executive branch (including the Council on Environmental Quality and the Office of Management and Budget) and the Congress to support adaptive management concepts is also necessary. It may be possible to obtain a general concurrence regarding the need to accommodate uncertainty by "learning while doing." Stronger commitments to adaptive management, however, may be stymied because of concerns that it may entail rising costs over time in a political environment that encourages firm cost estimates. Longer-term cost savings and benefits that adaptive management aims for through monitoring, analysis, and communication are often not readily apparent in its implementation stages. Reviews of previous adaptive management efforts demonstrate that the failure to conduct and maintain adequate monitoring is a principal reason why adaptive management fails (Walters, 1997). **Congress should thus allocate funding and personnel resources to help support and sustain an adaptive management program within the Corps (Recommendation 7).**

As this section has described, current policy guidance and budgeting procedures inhibit adaptive management practices. In the case of new Corps projects, the Corps has chosen to limit adaptive management expenditures to no more than three percent of the overall project cost and to a limited duration. In addition, most projects require a local sponsor to share in initial project costs and assume full responsibility of all post implementation costs. Adaptive management is a process that is different than traditional brick and mortar civil works construction, and it will often entail benefits that extend beyond the interests of a local project co-

sponsor. **The administration and the Congress should thus consider revising cost sharing formulas to promote the application of adaptive management principles (Recommendation 8).**

Interagency Relations

Even though interagency cooperation poses many challenges, some interagency water management programs or collaborations mandated by Congress have been useful. The Upper Mississippi Environmental Management Program (EMP), created in the 1986 Water Resources Development Act, is operated with the cooperation of the Corps and the U.S. Fish and Wildlife Service and the U.S. Geological Survey. The EMP has sponsored wetland restoration projects and, through its ecosystem monitoring component, provided much of the scientific basis for the 1999 Upper Mississippi River ecological status and trends report (USGS, 1999). The interagency cooperation brokered through the EMP has helped the Corps, the U.S. Department of the Interior, and state agencies in the Upper Mississippi River initiate experimental drawdowns. The interagency Louisiana Coastal Wetlands Conservation and Restoration Task Force operating under the Coastal Wetlands Planning, Protection and Restoration Act has planned and implemented numerous smaller restoration projects and, together with the state, produced the more comprehensive 2050 Plan. The Departments of the Army, Interior, Commerce, Agriculture, and the Environmental Protection Agency are represented on the Task Force and these same agencies are involved in the Louisiana Comprehensive Coastwide Ecosystem Feasibility Study. On the other hand, recent criticisms from the General Accounting Office regarding the inadequacy of interagency coordination in the Comprehensive Everglades Restoration Plan demonstrate that conflicts in agency priorities and limitations of interagency decision making can be significant obstacles in even well-funded programs. Beyond programs in which the Corps participates, in 1995 Congress created the Adaptive Management Program for managing the Colorado River in the Grand Canyon. The AMP has convened agencies, tribes, and interest groups for discussions on science-based management of the Colorado River ecosystem. In some instances, federal and state legislative action may be needed to create institutions to promote ecosystem restoration.

Inter-agency arrangements for natural resources management are not cure-alls and have not always resulted in expected improvements in, for example, ecological conditions. They have, however, provided fora for

dialogue, have helped improve scientific understanding, and have encouraged communication among stakeholder groups. In some settings, memoranda of agreement may be useful to assign authority and responsibility among agencies, and to establish a dispute resolution procedure(s). Particularly in complex, inter-jurisdictional ecosystem restoration projects, participation of other federal and state resource management agencies may be essential, either because of their stewardship responsibilities or their capacity to contribute to monitoring and assessment needed for adaptive management. Although the Corps has a great deal of expertise germane to adaptive management, the agency likely does not possess the collective scientific expertise necessary to implement and sustain the multifaceted components of adaptive management. Complexities of program execution and the limitations of the Corps' resources will require the Corps to collaborate with other agencies if adaptive management is to be efficiently pursued. Examples of federal agencies with whom the Corps should collaborate include the Environmental Protection Agency, the National Park Service, NOAA Fisheries and the U.S. Fish and Wildlife Service, and the U.S. Geological Survey. **The administration should strengthen federal interagency coordination mechanisms for large-scale water resources and coastal management efforts at both the national and regional levels (Recommendation 9).**

BROADER OPPORTUNITIES FOR IMPLEMENTING ADAPTIVE MANAGEMENT

Several areas of activity beyond the Corps' construction and ecosystem restoration programs offer opportunities for implementing adaptive management. These include smaller projects conducted under existing congressional authority, management of existing water resource infrastructure (especially dam reauthorization and deauthorization), and permitting activities. In these cases, adaptive management approaches may facilitate improvement of individual projects and development of an expanding knowledge base for improving future project operations.

Small Projects Authority

Small project programs are excellent candidates for experimentation and concerted learning in connection with adaptive management efforts. The Corps has the ability to change administration of these programs to allow for cost-shared modifications in project features based on long-term monitoring results of physical project outputs and ecological outcomes. Such changes would require no additional congressional authority. These changes could generate important demonstrations of the value of adaptive management and provide a basis for seeking additional congressional authority to revisit completed and ongoing projects that could benefit from adaptive management. Such settings would also allow the Corps to gain experience with smaller-scale and less controversial projects, lessons from which could be valuable in their efforts in more controversial situations.

Managing Existing Infrastructure

Effective operations of existing dams and other water resource infrastructure in the United States presents a challenge and an opportunity to the Corps and other federal water management agencies, as well as state and local governments and non-governmental organizations. Three key issues in management of this infrastructure could benefit from management criteria or guidelines that incorporate adaptive management: (1) monitoring and evaluating dam and project performance; (2) retrofitting, redesigning and operating dams to improve infrastructure safety and project performance; and (3) decommissioning, where warranted by costs and benefits. The Corps, with its varying involvement in design, permitting, construction, and operation of many of these structures, is the logical agency to assume the necessary responsibilities.

Passage of the Dam Safety and Security Act in 2002 points to increased congressional concern for dam safety issues. The Federal Emergency Management Agency (FEMA) coordinates federal dam safety efforts, helps finance research, coordinates technology transfer, and assists states with their dam safety programs (which cover approximately 95 percent of dams listed in the National Inventory of Dams). FEMA is not responsible, however, for improving dam safety technology or the engineering and science on which that technology is based. That would be a logical responsibility for the Corps, in cooperation with other organizations.

A promising area of application of adaptive management involves dam decommissioning and de-authorization. Although a dam cannot be incrementally removed, adaptive learning based upon the experiences with past dam removals should be used to refine the criteria and approaches for removals, and to improve methods for post-removal mitigation. As the Corps Inventory of Dams describes, over 75,000 dams have been erected on U.S. waterways, many of which are outdated, unsafe, and no longer active. Some of these structures have also caused significant impacts on river ecosystems. In recent years, the decommissioning and removal of dams has become more common. Hundreds of U.S. dams were removed in the 1990s, and removal of many more is being considered. Not all of these are small structures. A seminal case was the Quaker Neck Dam on North Carolina's Neuse River, where the Corps worked with the U.S. Fish and Wildlife Service and other federal and state agencies to remove a dam that had blocked migratory fish routes since 1952. In addition to ecological impacts, maintenance of Quaker Neck Dam had become hazardous and expensive. After the Corps designed alternative means of providing cooling water to the related power plant, a cooperative effort resulted in dam removal in 1997-98.

Permitting Activities

Adaptive management could also be usefully applied to the Corps' permitting activities. For example, the Corps is responsible for evaluating applications for wetland fill permits under Clean Water Act section 404. Corps regulations prohibit any filling unless appropriate and practicable steps have been taken to minimize adverse impacts on aquatic ecosystems. When the Corps issues a permit, it requires that discharges to wetlands be avoided or minimized to the extent practicable. Remaining impacts must be mitigated, often through compensatory mitigation, in which other wetlands are created or restored. An previous NRC committee concluded that compensatory mitigation was not fulfilling its goal of achieving no net loss of wetlands because clear performance standards were not being defined within permits and performance was not being monitored (NRC, 2001a). Although detailed evaluation of the regulatory program is beyond this report's scope, adaptive management principles could help the Corps improve its wetland mitigation program. Performance goals could be set in permits, and permitees could be required to implement a monitoring program focused on wetland functions. Alternatively or additionally, the Corps could conduct a retrospective study(s) of

mitigation projects, and use the results to improve design of future mitigation efforts. Adaptive management principles could also be used to guide permitting decisions and mitigation requirements in which cumulative impacts are an issue, such as where multiple permits are issued for the same water body.

COMMENTARY

The Corps should begin to develop a framework for adaptive management guidance throughout the organization. Without agency-wide guidance, the Corps' current adaptive management efforts are more likely to proceed in fits and starts. Moreover, the failure to better document and share lessons from initial experiences represents lost opportunities. In developing operational guidance for adaptive management, the Corps should provide guidance concerning the degree to which adaptive management is applicable to various projects. Some Corps programs could benefit simply from periodic, adaptive re-evaluation. Passive adaptive management could be applied to projects not easily replicated or otherwise based on robust models of performance. A more active adaptive management approach, exploring multiple project or operational alternatives, could be used where there is a high level of uncertainty about the outcomes of these alternatives.

In many ways, adaptive management represents a paradigm shift for the Corps. Given the usual inertia in large organizations like the Corps, the approach will not be systematically implemented throughout the agency immediately. As the Corps proceeds with its efforts in adaptive management, a Center for Adaptive Management that tracks adaptive management experiences within the Corps, shares lessons throughout the organization, and develops general adaptive management definitions and principles, would be valuable. The Corps should also shift its traditional orientation from primarily constructing new projects, to closer monitoring and evaluation and more efficient operations of existing projects. The Corps should seek the advice of experts from outside the agency as it moves forward with adaptive management.

Beyond the Corps, support for adaptive management from the Congress and the administration is essential. The Corps should have more authority and flexibility in the area of post-construction activities, such as ecosystem monitoring and project evaluation. The Corps also operates in confusing legal settings where it is obligated to uphold dozens, if not hundreds, of pieces of legislation and other guidance. In these set-

tings, the agency often appears reluctant to depart from the status quo, but lacks clear direction from the administration and Congress on the appropriate way forward. Nevertheless, the Corps is attempting some adaptive management activities, such as navigation pool drawdowns, habitat restoration projects, and ecosystem monitoring. These are steps in the right direction, and small steps can be useful in learning more about ecological responses, building interagency partnerships, and establishing trust with stakeholder groups. But for larger gains from adaptive management to be realized, the Congress and the administration must step forward and resolve internally-inconsistent legislation and guidance, establish or invigorate interagency fora, commit support to science-based, collaborative programs, and adjust traditional authorization and appropriations processes.

6

Epilogue

The U.S. Army Corps of Engineers has long experienced successes in designing and constructing federal water resources projects, and the agency enjoyed a long period during which its engineering expertise and decisions were respected and often deferred to. The setting of federal water resources planning and management, however, changed markedly during the late twentieth century. Federal spending on water projects declined markedly, public scrutiny and concerns over environmental impacts continued to increase, and project management assumed a more interdisciplinary character. Paradoxically, it was often great Corps successes that contributed to economic development and growth of supporting social institutions, which now understandably resist change.

New water resources projects will continue to be implemented, some of which will continue to provide traditional benefits related to navigation and flood control; however, given the large degree of influence that Corps civil works projects exert on the nation's hydrologic systems, management of the infrastructure has become a more important issue. Moreover, present and future civil works projects are being and will be constructed to achieve a broader range of objectives, especially ecosystem restoration. The Corps has made some changes in response to these shifting conditions, but the pace and the scale of these changes have challenged the ability of a large organization like the Corps to fully adapt to them.

If the Corps is to adjust successfully to this contemporary setting, it will need to change from an agency geared almost exclusively to constructing new projects, to one that with broader concerns and that emphasizes the importance of managing an existing water control infrastructure in a context of broadening social objectives. As this report has explained, the adaptive management approach provides a basis for anticipating and adjusting to present uncertainties and future changes. Adaptive management does not represent a panacea for solving all water conflicts and management challenges, and it may eventually be replaced by different, more promising management paradigm, but it currently holds

good prospects for helping the Corps adjust to future challenges and unforeseen changes. The nation will continue to need credible engineering expertise to help manage its existing water control infrastructure. If the Corps is to provide that expertise, its planning orientation, functions, and activities will require the types of changes to the adaptive type of approaches recommended in this report.

If the Corps is to develop the approaches and capabilities required for twenty-first century water resources management, it will need assistance from the administration and from the Congress. The Corps must have the resources and authorities to apply its knowledge and capabilities to today's complex water management problems, including interactions with the public and other agencies. The administration and the Congress must provide clearer advice regarding national priorities within a large body of overlapping and potentially conflicting laws and authorities that often encumbers Corps decision making. The administration and the Congress must provide resources for the execution of new Corps activities—such as evaluating ecological and economic outcomes of project operations—that are essential to sound water management according to contemporary principles and knowledge. This type of support will be essential to refocusing and strengthening the Corps' management capabilities, and to helping the agency support the sound water management practices that will be of continued importance to the nation.

References

Anderson, J. L., R. W. Hilborn, R. T. Lackey, and D. Ludwig. 2003. Watershed restoration: Adaptive decision making in the face of uncertainty. In Wissmar, R. C., and P. A. Bisson (eds.) Strategies for Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems. Bethesda, MD: American Fisheries Society.

Barry, J. M. 1997. Rising Tide: The Great Mississippi Flood of 1927 and How it Changed America. New York, NY: Simon and Schuster.

Blake, N. M. 1980. Land into Water—Water into Land: A History of Water Management in Florida. Tallahassee: University Presses of Florida.

Boesch, D. F., M. J. Josselyn, A. J. Mehta, J. T. Morris, W. K. Nuttle, C. A. Simenstad, and D. J. P. Swift. 1994. Scientific assessment of coastal wetland loss, restoration and management in Louisiana. Journal of Coastal Restoration Special Issue 20: 103.1-103.

Boulding, K. 1981. Basic Evolutionary Model. Evolutionary Economics. Beverly Hills, CA: Sage Publications.

Brewer, G. D. 1975. An analyst's view of the uses and abuses of modeling for decision making. Rand Corporation Paper P-5395.

Carrels, P. 1999. Uphill Against Water: The Great Dakota Water War. Lincoln, NE: University of Nebraska Press.

Clarke, J. N., and D. C. McCool. 1996. Staking Out the Terrain. 2nd Edition. Albany, NY: State University of New York Press.

Cyert, R. M., and J. G. March. 1963. A Behavioral Theory of the Firm. Englewood Cliffs, NJ: Prentice-Hall, Inc.

De Neufville, R. 1990. Applied Systems Analysis: Engineering Planning and Technology Management. New York, NY: McGraw-Hill.

De Neufville, R. 2000. Dynamic strategic planning for technology policy. International Journal of Technology Management 19(3/4/5): 225-245.

De Neufville, R., and A. R. Odoni. 2003. The Forecast is Always Wrong. In De Neufville, R. and A.R. Odoni (eds.) Airport Systems

Planning, Design, and Management. New York, NY: McGraw-Hill.

De Neufviille, R. 2004. Uncertainty Management for Engineering Systems Planning and Design. Faculty Monograph, MIT Engineering Systems Symposium, Cambridge, MA, March 2004.

Deschutes Resources Conservancy Website. 2003. Available online at *http://www.deschutesrc.org/index.htm,* accessed May 21, 2003.

Dewey, J. 1938. Experience and Education. New York, NY: Macmillan.

Doremus, H. 2001. Adaptive management, the Endangered Species Act, and the institutional challenges of "new age" environmental protection. Washburn Law Journal 41:50-89.

EDF (Environmental Defense Fund). 1995. Restoring Oregon's Deschutes River: Developing Partnerships and Economic Incentives to Improve Water Quality and Instream Flows. New York, NY: Environmental Defense Fund.

Everett, E. A., Jr., and R. J. Ebert. 1986. Production and Operations Management: Concepts, Models, and Behavior. Engelwood Cliffs, NJ: Prentice-Hall.

Ferejohn, J. A. 1974. Pork Barrel Politics. Stanford, CA: Stanford University Press.

Ferrell, J. 1996. Soundings. Omaha, NE: United States Army Corps of Engineers.

FWS (United States Fish and Wildlife Service). 2000. Final Missouri River Biological Opinion. Washington DC: United States Fish and Wildlife Service.

GAO (United States General Accounting Office). 2003. South Florida Ecosystem Restoration: Task Force Needs to Improve Science Coordination to Increase the Likelihood for Success. GAO-03-345. Washington, DC: Government Printing Office.

Gunderson, L. 1999. Resilience, flexibility and adaptive management—Antidotes for spurious certitude? Conservation Ecology 3(1):7. Available online at *http://www.consecol.org/vol3/iss1/ art7*, February 13, 2003.

Gunderson, L. 2000. Resilience in theory and practice. Annual Review of Ecology and Systematics 31:425-439.

Häfele, W., and R. Bürk. 1976. An attempt of log-range macroeconomic modeling in view of structural and technological change. IASA RM-76-32.

Hays, S. P. 1999. Conservation and the Gospel of Efficiency. Pittsburg, PA: University of Pittsburg Press.

Holling, C. S. (ed.). 1978. Adaptive Environmental Assessment and Management. New York, NY: John Wiley and Sons.

Jacobs, J. W. 2002. Broadening U.S. water resources project planning and evaluation. Natural Resources Journal 42(1): 21-31.

Jacobs, J. W., and J. L. Wescoat, Jr. 2002. Managing river resources: Lessons from Glen Canyon Dam. Environment 44(2): 8-19.

Johnson, B. L. 1999. The Role of Adaptive Management as an Operational Approach for Resource Management Agencies. Conservation Ecology 3(2):8. Available online at *http://www.consecol.org/vol3/iss2/art8*, accessed February 13, 2003.

Johnston, J. B., M. C. Watzin, J. A. Barras, and L. R. Handley. 1995. Gulf of Mexico Coastal Wetlands: Case Studies of Loss Trends. In LaRoe, E. T., G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, (eds.). Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems. Washington, DC: U.S. Department of the Interior, National Biological Service.

Keeney, R. L. 1997. A utility function for examining policy affecting salmon in the Skeena River. Journal of the Fisheries Research Board of Canada (34): 49-63.

Kenney, D. S. 2000. Arguing About Consensus. Boulder, CO: University of Colorado School of Law.

Lane, R. R., J. W. Day, Jr., and B. Thibodeaux. 1999. Water quality analysis of a freshwater diversion at Caernarvon, Louisiana. Estuaries 22: 327-336.

League, I. W. 2003. Refuge at the Crossroads: Recommendations. Available online at *http://www.iwla.org/reports/ref_rcmd.html*, accessed July 28, 2003.

Lee, K. N. 1993. Compass and Gyroscope: Integrating Science and Politics for the Environment. Washington, DC: Island Press.

Lee, K. N. 1999. Appraising Adaptive Management. Conservation Ecology 3(2):3. Available online at *http://www.consecol.org/vol3/iss2/art3*, accessed February 13, 2003.

Lewis, J. A. 1948. Soils, Geology, and Water Control in the Everglades Region. Gainesville, FL: University of Florida Agricultural Experiment Station.

Lindblom, C. 1957. The science of muddling through. Public Administration Review 19 (1): 79-88.

Lindblom, C. 1979. Still muddling, not through yet. Public Administration Review 39: 517-526.

Louisiana DNR (Department of Natural Resources). 1999. Louisiana Coast Lines: Coast 2050 Plan Approved. Available online at *http://www.dnr.state.la.us/crm/coastmgt/coastlns/lcl0399.pdf*, accessed February 27, 2004.

Lubinski, K., and J. Barko. 2003. Upper Mississippi River-Illinois Waterway System Navigation Feasibility Study: Environmental Science Panel Report. Draft. Report. Rock Island, IL, St. Louis, MO, and St. Paul, MN: U.S. Army Corps of Engineers.

Maass, A. 1951. Muddy Waters. Cambridge, MA: Harvard University Press.

McLain, R. J., and R. G. Lee. 1996. Adaptive management: Promises and pitfalls. Environmental Management 20: 437-438.

Murray–Darling Basin Commission Website. 2003. Available online at *http://www.mdbc.gov.au/*, accessed May 21, 2003.

Nancarrow, B. E., and G. J. Syme. 2001. River Murray Environment Flows and Water Quality Project: Stakeholder Profiling Study. Available online at *http://www.mdbc.gov.au/whatson/PDF/stakh-report.pdf*, accessed May 21, 2003.

NRC (National Research Council). 1996. Upstream: Salmon and Society in the Pacific Northwest. Washington, D.C.: National Academy Press.

NRC. 1999. Downstream: Adaptive Management of Glen Canyon Dam and the Colorado River Ecosystem. Washington, D.C.: National Academy Press.

NRC. 2001a. Aquifer Storage and Recovery in the Comprehensive Everglades Restoration Plan. Washington, DC: National Academy Press.

NRC. 2001b. Assessing the TMDL Approach to Water Quality Management. Washington, D.C.: National Academy Press.

NRC. 2001c. Compensating for Wetland Losses Under the Clean Water Act. Washington, D.C.: National Academy Press.

NRC. 2001d. Inland Navigation System Planning: The Upper Mississippi River-Illinois Waterway. Washington, D.C.: National Academy Press.

NRC. 2002. The Missouri River Ecosystem: Exploring the Prospects for Recovery. Washington, D.C.: National Academy Press.

NRC. 2003a. Adaptive Monitoring and Assessment for the Comprehensive Everglades Restoration Plan. Washington, D.C.: The National Academies Press.

NRC. 2003b. Environmental Cleanup at Navy Facilities: Adaptive Site Management: Washington, D.C.: The National Academies Press.

NRC. 2003c. One Step at a Time: The Staged Development of Geologic Repositories for High-Level Radioactive Waste. Washington, D.C.: The National Academies Press.

National Resources Committee. 1938. Drainage Basin Problems and Programs. Prepared by the Water Resources Committee. Washington, DC: Government Printing Office.

Parma, A. M., and NCEAS Working Group on Population Management. 1998. What can adaptive management do for our fish, forests, food, and biodiversity? Integrative Biology 1:16-26.

Peat, F. D. 2002. From Certainty to Uncertainty: The Story of Science and Ideas in the Twentieth Century. Washington, DC: Joseph Henry Press.

Pickett, S. T., J. Kolasa, and C. G. Jones. 1994. Ecological Understanding: The Nature of Theory and the Theory of Nature. San Diego, CA: Academic Press.

Regan, H. M., M. Colyvan, and M. A. Burgman. 2002. A taxonomy and treatment of uncertainty for ecology and conservation biology. Ecological Applications 12: 618-628.

Repetto, R., D. Rothman, P. Faeth and D. Austin. 1996. Has Environmental Protection Really Reduced Productivity Growth? We Need Unbiased Measures. Washington, DC: World Resources Institute.

Rhodes, S. L., D. Ely, and J. A. Dracup. 1984. Climate and the Colorado River: The limits of management. Bulletin of the American Meteorological Society 65: 682-691.

Salafsky, N., R. Margoluis, and K. Redford. 2001. Adaptive Management: A Tool for Conservation Practitioners. Washington, DC: Biodiversity Support Program.

Scudder, T. 1994. Recent Experiences with River Basin Development in the Tropics and Subtropics. Natural Resources Forum, Vol. 18.

Shindler, B. and K.A. Cheek. 1999. Integrating Citizens in Adaptive Management: A Propositional Analysis. Conservation Ecology 3(1): 9. Available online at *http://www.consecol.org/vol3/iss1/art9*, accessed May 21, 2003.

UMBRA (Upper Mississippi River Basin Authority). 1995. Forging a New Framework for the Future: A Report to the Governors on State and Federal Management of the Upper Mississippi River. Available online at *http://www.umrba.org/reports/rptgov.pdf*, accessed May 21, 2003.

UMBRA and GLC (Upper Mississippi River Basin Authority and Governors Liaison Committee). 2003. Comments of the Upper Mississippi River Basin Association and Governors Liaison Committee on

the Upper Mississippi River-Illinois Waterway Navigation Feasibility Study Memorandum for the Record regarding Ecosystem Restoration: Discussion of Authorities and Cost Sharing Options. Draft, revised June 25, 2003.

USACE (United States Army Corps of Engineers). 1994. Volume 6C: Economic Studies, Recreation Economics. In Master Manual. United States Army Corps of Engineers, Northwestern Division.

USACE. 1997. Report to Congress: An Evaluation of the Upper Mississippi River System Environmental Management Program. Rock Island, IL: United States Army Corps of Engineers.

USACE. 1998. Volume 6A-R: Economic Studies, Navigation Economics (Revised). In: Master Water Control Manual, Missouri River Review and Update Study. Omaha, NE: USACE Northwest Division, Missouri River Region.

USACE. 1999. Central and Southern Florida Project Comprehensive Review Study, Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. Jacksonville, FL: U.S. Army Corps of Engineers.

USACE. 2000a. Missouri River Mainstem Reservoirs Summary of Actual 1998-1999 Operations. United States Army Corps of Engineers, Northwestern Division.

USACE. 2000b. The U.S. Waterway System—Transportation Facts United States Army Corps of Engineers, Navigation Data Center.

USACE. 2001a. Civil Works Programs. IWR Report 98-R-3. Revised June, 2001. Alexandria, VA: Institute for Water Resources.

USACE, 2001b. Summary of the Missouri River Environmental Impact Statement: Revised Draft. Master Water Control Manual, Review and Update. Omaha, NE: USACE, Northwest Division.

USACE. 2002. Programmatic Regulations for the Comprehensive Everglades Restoration Plan. 33 CFR Part 385. RIN 0710-AA49. Federal Register, Vol. 67, No. 149. Available online at *http://www.evergladesplan.org/pm/pm_docs/prog_regulations/proposed_rule_080202.pdf*, accessed July 28, 2003.

USACE and SFWMD (U.S. Army Corps of Engineers and the South Florida Water Management District). 2002. The Comprehensive Everglades Restoration Plan: Development and Study Goals. Available online at *http:www.evergladesplan.org/about/rest_plan.cfm*, accessed July 1, 2004.

U.S. Bureau of Reclamation. 1995. Operation of Glen Canyon Dam: Final Environmental Impact Statement. Washington, D.C.: U.S. Bureau of Reclamation.

USGS (United States Geological Survey). 1997. Missouri River Environmental Assessment Program. Washington DC: United States Geological Survey.

USGS. 1999. Ecological Status and Trends of the Upper Mississippi River System 1998: A Report of the Long Term Resource Monitoring Program. Available online at *http://www.umesc.usgs.gov/reports_publications/status_and_trends.html*, accessed June 11, 2003.

USGS. 2003. CWPPRA's Restoration Projects. Available online at *http://www.lacoast.gov/projects/list.asp*, accessed July 28, 2003.

Walters, C. J. 1986. Adaptive Management of Renewable Resources. New York, NY: Macmillan.

Walters, C. J. 1997. Challenges in Adaptive Management of Riparian and Coastal Ecosystems. Conservation Ecology 1(2):1. Available online at *http://www.consecol.org/vol1/iss2/art1*, accessed February 13, 2003.

Walters, C. J., and C. S. Holling. 1990. Large-scale management experiments and learning by doing. Ecology 71: 2060-2068.

Water Resources Council. 1983. Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies. Washington, DC: Government Printing Office.

White, G. F. 1961. The choice of use in resource management. Natural Resources Journal 1(March):23-40.

White, G. F. 1988. When May a Post-Audit Teach Lessons? In The Flood Control Challenge: Past, Present, and Future. Washington, DC: Public Works Historical Society.

WCD (World Commission on Dams). 2000. Dams and Development: A New Framework for Decision-Making. London: Earthscan.

Acronyms

AMP	Adaptive Management Program
AMWG	Adaptive Management Working Group
AOP	annual operating plan
CAC	community advisory committee
CERP	Comprehensive Everglades Restoration Plan
CIA	computerized inventory and analysis
CROGEE	Committee on Restoration of the Greater Everglades Ecosystem
CWPPRA	Coastal Wetlands Planning, Protection and Restoration Act
EIS	environmental impact statement
EMP	Environmental Management Program
FEMA	Federal Emergency Management Agency
GAO	U.S. General Accounting Office
GCMRC	Grand Canyon Monitoring and Research Center
GDP	gross domestic product
HREP	habitat rehabilitation and enhancement project
IIASA	International Institute for Applied Systems Analysis
LCA study	Louisiana Comprehensive Coastwide Ecosystems Restoration Feasibility Study
LTRMP	Long Term Resource Monitoring Program
MDBC	Murray-Darling Basin Commission
NCEAS	National Center for Ecological Analysis and Synthesis
NRC	National Research Council
OMB	Office of Management and Budget
P&G	Principles and Guidelines
RECOVER	Restoration, Coordination, and Verification
SFWMD	South Florida Water Management District
TMDL	total maximum daily load
TWG	technical working group
UMESC	Upper Midwest Environmental Science Center

UMRBA	Upper Mississippi River Basin Association
UMR-IWW	Upper Mississippi River-Illinois Waterway
USACE	U.S. Army Corps of Engineers
WRC	Water Resources Council
WRDA	Water Resources Development Act

Appendixes

Appendix A

Water Resources Development Act 2000
Public Law No. 106-541, of the 106th Congress

SEC. 216. NATIONAL ACADEMY OF SCIENCES STUDY.

(a) DEFINITIONS—In this section, the following definitions apply:

(1) ACADEMY—The term "Academy" means the National Academy of Sciences.

(2) METHOD—The term "method" means a method, model, assumption, or other pertinent planning tool used in conducting an economic or environmental analysis of a water resources project, including the formulation of a feasibility report.

(3) FEASIBILITY REPORT—The term "feasibility report" means each feasibility report, and each associated environmental impact statement and mitigation plan, prepared by the Corps of Engineers for a water resources project.

(4) WATER RESOURCES PROJECT—The term "water resources project"' means a project for navigation, a project for flood control, a project for hurricane and storm damage reduction, a project for emergency streambank and shore protection, a project for ecosystem restoration and protection, and a water resources project of any other type carried out by the Corps of Engineers.

(b) INDEPENDENT PEER REVIEW OF PROJECTS—

(1) IN GENERAL—Not later than 90 days after the date of enactment of this Act, the Secretary shall contract with the Academy to study, and make recommendations relating to, the independent peer review of feasibility reports.

(2) STUDY ELEMENTS—In carrying out a contract under paragraph (1), the Academy shall study the practicality and efficacy of the independent peer review of the feasibility reports, including—

(A) the cost, time requirements, and other considerations relating to the implementation of independent peer review; and

(B) objective criteria that may be used to determine the most effective application of independent peer review to feasibility reports for each type of water resources project.

(3) ACADEMY REPORT—Not later than 1 year after the date of a contract under paragraph (1), the Academy shall submit to the Secretary, the Committee on Transportation and Infrastructure of the House of Representatives, and the Committee on Environment and Public Works of the Senate a report that includes—

(A) the results of the study conducted under paragraphs (1) and (2); and

(B) in light of the results of the study, specific recommendations, if any, on a program for implementing independent peer review of feasibility reports.

(4) AUTHORIZATION OF APPROPRIATIONS—There is authorized to be appropriated to carry out this subsection $1,000,000, to remain available until expended.

(c) INDEPENDENT PEER REVIEW OF METHODS FOR PROJECT ANALYSIS—

(1) IN GENERAL—Not later than 90 days after the date of enactment of this Act, the Secretary shall contract with the Academy to conduct a study that includes—

(A) a review of state-of-the-art methods;

(B) a review of the methods currently used by the Secretary;

(C) a review of a sample of instances in which the Secretary has applied the methods identified under subparagraph (B) in the analysis of each type of water resources project; and

(D) a comparative evaluation of the basis and validity of state-of-the-art methods identified under subparagraph (A) and the methods identified under subparagraphs (B) and (C).

(2) ACADEMY REPORT—Not later than 1 year after the date of a contract under paragraph (1), the Academy shall transmit to the Secretary, the Committee on Transportation and Infrastructure of the House of Representatives, and the Committee on Environment and Public Works of the Senate a report that includes—

(A) the results of the study conducted under paragraph (1); and

(B) in light of the results of the study, specific recommendations for modifying any of the methods currently used by the Secretary for conducting economic and environmental analyses of water resources projects.

(3) AUTHORIZATION OF APPROPRIATIONS—There is authorized to be appropriated to carry out this subsection $2,000,000. Such sums shall remain available until expended.

Appendix B

Rosters

Coordinating Committee

LEONARD SHABMAN, Chair, Resources for the Future, Washington, D.C.
GREGORY B. BAECHER, University of Maryland, College Park
DONALD F. BOESCH, University of Maryland, Cambridge
ROBERT W. HOWARTH, Cornell University, Ithaca, New York (*through November 2002*)
GERALDINE KNATZ, Port of Long Beach, Long Beach, California
JAMES K. MITCHELL, Virginia Polytechnic Institute and State University, Blacksburg
LARRY A. ROESNER, Colorado State University, Fort Collins (*through August 2003*)
A. DAN TARLOCK, Chicago-Kent College of Law, Chicago, Illinois
VICTORIA J. TSCHINKEL, The Nature Conservancy, Altamonte Springs, Florida
JAMES G. WENZEL, Marine Development Associates, Inc., Saratoga, California
M. GORDON WOLMAN, Johns Hopkins University, Baltimore, Maryland

Peer Review Procedures

JAMES K. MITCHELL, Chair, Virginia Polytechnic Institute and State University, Blacksburg
MELBOURNE BRISCOE, Office of Naval Research, Arlington, Virginia
STEPHEN J. BURGES, University of Washington, Seattle
LINDA CAPUANO, Honeywell, Inc., San Jose, California
DENISE FORT, University of New Mexico, Albuquerque
PORTER HOAGLAND, Woods Hole Oceanographic Institution, Massachusetts
DAVID H. MOREAU, University of North Carolina, Chapel Hill
CRAIG PHILIP, Ingram Barge Company, Nashville, Tennessee
JOHN T. RHETT, Consultant, Arlington, Virginia

RICHARD E. SPARKS, Illinois Water Resources Center, Urbana
BORY STEINBERG, Steinberg and Associates, McLean, Virginia

Panel on Methods and Techniques of Project Analysis
GREGORY B. BAECHER, Chair, University of Maryland, College Park
JOHN B. BRADEN, University of Illinois, Urbana-Champaign
DAVID L. GALAT, University of Missouri, Columbia
GERALD E. GALLOWAY, Titan Corporation, Fairfax, Virginia
ROBERT G. HEALY, Duke University, Durham, North Carolina
EDWIN E. HERRICKS, University of Illinois, Urbana-Champaign
CATHERINE L. KLING, Iowa State University, Ames
LINDA A. MALONE, College of William and Mary, Williamsburg, Virginia
RAM MOHAN, Blasland, Bouck & Lee, Inc., Annapolis, Maryland
MAX J. PFEFFER, Cornell University, Ithaca, New York
DOUG PLASENCIA, AMEC, Phoenix, Arizona
DENISE J. REED, University of New Orleans, Louisiana
JAN A. VELTROP, Consultant, Skokie, Illinois

Adaptive Management for Resource Stewardship
DONALD F. BOESCH, Chair, University of Maryland-Center for Environmental Science, Cambridge
HENRY J. BOKUNIEWICZ, University of New York, Stony Brook
RICHARD DE NEUFVILLE, Massachusetts Institute of Technology, Cambridge
G. EDWARD DICKEY, Consultant, Baltimore, Maryland
HOLLY D. DOREMUS, University of California, Davis
FREDRICK HITZHUSEN, Ohio State University, Columbus
CARL H. HERSHNER, Virginia Institute of Marine Science, Gloucester Point, Virginia
FREDERICK J. HITZHUSEN, Ohio State University, Columbus
CHARLES D. D. HOWARD, Charles Howard Associates, British Columbia, Canada
WILLIAM R. LOWRY, Washington University, St. Louis, Missouri
BARRY R. NOON, Colorado State University, Fort Collins
THAYER SCUDDER, California Technology Institute, Pasadena
ROBERT W. STERNER, University of Minnesota, Minneapolis

River Basin and Coastal Systems Planning
PETER R. WILCOCK, Chair, Johns Hopkins University, Baltimore, Maryland

GAIL M. ASHLEY, Rutgers University, Piscataway, New Jersey
DENISE L. BREITBURG, Smithsonian Environmental Research Center, Edgewater, Maryland
VIRGINIA R. BURKETT, U.S. Geological Survey, Lafayette, Louisiana
JOSEPH J. CORDES, George Washington University, Washington, D.C.
ROBERT G. DEAN, University of Florida, Gainesville
JOHN A. DRACUP, University of California, Berkeley
WILLIAM J. MITSCH, Ohio State University, Columbus
ROBERT E. RANDALL, Texas A&M University, College Station
A. DAN TARLOCK, Chicago Kent College of Law, Chicago, Illinois

Water Science and Technology Board
RICHARD G. LUTHY, Chair, Stanford University, Stanford, California
JOAN B. ROSE, Vice Chair, Michigan State University, East Lansing
RICHELLE M. ALLEN-KING, State University of New York (SUNY), Buffalo, New York
GREGORY B. BAECHER, University of Maryland, College Park
KENNETH R. BRADBURY, Wisconsin Geological and Natural History Survey, Madison
JAMES CROOK, Water Reuse Consultant, Norwell, Massachusetts
EFI FOUFOULA-GEORGIOU, University of Minnesota, Minneapolis
PETER GLEICK, Pacific Institute for Studies in Development, Environment, and Security, Oakland, California
JOHN LETEY, JR., University of California, Riverside
DIANE M. MCKNIGHT, University of Colorado, Boulder (*through June 30, 2003*)
CHRISTINE L. MOE, Emory University, Atlanta, Georgia
ROBERT PERCIASEPE, National Audubon Society, Washington, D.C.
RUTHERFORD H. PLATT, University of Massachusetts, Amherst (*through June 30, 2003*)
JERALD L. SCHNOOR, University of Iowa, Iowa City
LEONARD SHABMAN, Resources for the Future, Washington, D.C.
R. RHODES TRUSSELL, Trussell Technologies, Inc., Pasadena, California
KARL K. TUREKIAN, Yale University, New Haven, Connecticut
HAME M. WATT, Independent Consultant, Washington, D.C.
JAMES L. WESCOAT, JR., University of Illinois at Urbana-Champaign

Water Science and Technology Board Staff
STEPHEN D. PARKER, Director
LAURA J. EHLERS, Senior Staff Officer
JEFFREY W. JACOBS, Senior Staff Officer
WILLIAM S. LOGAN, Senior Staff Officer
LAUREN E. ALEXANDER, Staff Officer
MARK C. GIBSON, Staff Officer
STEPHANIE E. JOHNSON, Staff Officer
M. JEANNE AQUILINO, Administrative Associate
ELLEN A. DE GUZMAN, Research Associate
PATRICIA JONES KERSHAW, Study/Research Associate
ANITA A. HALL, Administrative Assistant
JON Q. SANDERS, Senior Project Assistant
DOROTHY K. WEIR, Project Assistant

Ocean Studies Board
NANCY RABALAIS (*Chair*), Louisiana Universities Marine Consortium, Chauvin
LEE G. ANDERSON, University of Delaware, Newark
WHITLOW AU, University of Hawaii at Manoa
ARTHUR BAGGEROER, Massachusetts Institute of Technology, Cambridge
RICHARD B. DERISO, Inter-American Tropical Tuna Commission, La Jolla, California
ROBERT B. DITTON, Texas A&M University, College Station
EARL DOYLE, Shell Oil (Retired), Sugar Land, Texas
ROBERT DUCE, Texas A&M University, College Station
PAUL G. GAFFNEY, II, National Defense University, Washington, D.C.
WAYNE R. GEYER, Woods Hole Oceanographic Institution, Massachusetts
STANLEY R. HART, Woods Hole Oceanographic Institution, Massachusetts
RALPH S. LEWIS, Connecticut Geological Survey (Retired), Hartford
WILLIAM F. MARCUSON, III, U.S. Army Corp of Engineers (Retired), Vicksburg, Mississippi
JULIAN P. MCCREARY, JR., University of Hawaii, Honolulu
JACQUELINE MICHEL, Research Planning, Inc., Columbia, South Carolina
JOAN OLTMAN-SHAY, Northwest Research Associates, Inc., Bellevue, Washington
ROBERT T. PAINE, University of Washington, Seattle

SHIRLEY A. POMPONI, Harbor Branch Oceanographic Institution, Fort Pierce, Florida
FRED N. SPIESS, Scripps Institution of Oceanography, La Jolla, California
DANIEL SUMAN, Rosentiel School of Marine and Atmospheric Science, Unviersity of Miami, Florida

Ocean Studies Board Staff
SUSAN ROBERTS, Director
JENNIFER MERRILL, Senior Program Officer
DAN WALKER, Senior Program Director
JOANNE BINTZ, Program Officer
ALAN B. SIELEN, Visiting Scholar
ANDREAS SOHRE, Financial Associate
SHIREL SMITH, Administrative Associate
JODI BACHIM, Senior Project Assistant
NANCY CAPUTO, Senior Project Assistant
SARAH CAPOTE, Project Assistant

Appendix C

Biographical Information of Panel Members and Staff

Donald F. Boesch is a professor of marine science and President of the University of Maryland Center for Environmental Science (UMCES). Dr. Boesch is a biological oceanographer who has studied coastal and continental shelf environments along the Atlantic Coast and in the Gulf of Mexico, eastern Australia, and the East China Sea. He has published two books and more than 60 papers on marine benthos, estuaries, wetlands, continental shelves, oil pollution, nutrient over-enrichment, environmental assessment and monitoring and science policy. In 1980 he returned to his native state as the first Executive Director of the Louisiana Universities Marine Consortium (LUMCON), where he was also a professor of marine science at Louisiana State University. He was a Fulbright Postdoctoral Fellow at the University of Queensland and subsequently served on the faculty of the Virginia Institute of Marine Science. Dr. Boesch received his B.S. degree from Tulane University and Ph.D. degree from the College of William Mary.

Henry J. Bokuniewicz is a professor at the Marine Sciences Research Center at the State University of New York at Stony Brook. His research interests include nearshore transport processes, coastal groundwater hydrology, coastal sedimentation, and marine geophysics. He is particularly interested in the behavior of coastal sedimentary systems and coastal groundwater hydrology and its relations to coastal zone management problems. He received his B.A. from the University of Illinois, and his M. Phil. and Ph.D. degrees from Yale University.

Richard de Neufville is a professor of engineering systems and of civil and environmental engineering at the Massachusetts Institute of Technology. From 1976-2000 he was the founding chair of the MIT Technology and Policy Program. Earlier, he was a White House Fellow for President Johnson. His research is in dynamic strategic planning and technology policy, engineering systems analysis and real options. He has written textbooks in these fields. Dr. de Neufville received his S.B.,

S.M. and Ph.D. degrees from MIT, and his Dr. hc. Degree from the Delft University of Technology.

G. Edward Dickey is a consultant to public and private organizations interested in water policy and infrastructure development and management. He also is adjunct professor of economics at Loyola College in Maryland. Dr. Dickey retired from federal service in 1998 after a career in water resources planning and project development. In his last position as Chief of the Planning Division of the U.S. Army Corps of Engineers, he directed the Corps' nationwide water resources planning programs and its small project programs. In his prior positions as Deputy Assistant Secretary of the Army and Acting Assistant Secretary of the Army (Civil Works), he provided leadership and policy direction for all army civil works activities including the Section 404 regulatory program. He received his B.A. degree in political economy from the Johns Hopkins University and his M.A. and Ph.D. degrees from Northwestern University.

Holly D. Doremus is a professor of law at the University of California, Davis. Before joining UC-Davis, she taught law at University of Oregon School of Law and Oregon State University, Corvallis. Previous to teaching, she was an associate at Eickelberg & Fewel at Corvallis, Oregon. Before entering law school, Dr. Doremus conducted basic research on metabolic pathways of plants but was always interested in how scientific data are integrated into a legal structure. She received her B.S. degree in biology from Trinity College, her Ph.D. degree from Cornell University, and her J.D. degree from the University of California, Berkeley.

Carl H. Hershner is an associate professor of marine science at the College of William and Mary. He directs the Center for Coastal Resources Management at the Virginia Institute of Marine Science. His research interests are in tidal and nontidal wetlands ecology, landscape ecology, and resource management/policy issues. He has active interests in resource inventory procedures, habitat restoration protocols, resource management "expert system" development, and science policy interactions. He received his B.S. degree from Bucknell University and his Ph.D. degree from the University of Virginia.

Fredrick J. Hitzhusen is a professor in the Department of Agricultural, Environmental, and Development Economics. His primary research in-

terests include the economics of sustainable agriculture, forest, and mining systems with emphasis on off-site soil sediment and water quality costs; the economics of renewable energy; and the economics of delivering and financing nonmetropolitan or rural government services. He received his B.S. degree in agricultural education from Iowa State University, his M.S. degree in agricultural economics from Purdue University, and his Ph.D. degree in resource economics from Cornell University.

Charles D. D. Howard was the Founder and past President of Charles Howard & Associates, Ltd. and has been an independent consulting engineer since 1969 in the field of water resources engineering. He has provided advice regarding water resource system operations and planning to water and power utilities, provincial, state, and federal governments in Canada and the U.S., the United Nations Development Programme (UNDP) and the World Bank. In 1998 he received the Julian Hinds Award of the American Society of Civil Engineers. He has participated in several National Research Council committees and boards including: Water Science and Technology Board, 1996-1999; Committee on Water Resources in the Middle East, 1995-98; and the Committee on Irrigation Water Quality Problems, 1987-96. Mr. Howard earned his B.S. and his M.S. degrees from the University of Alberta, and his M.S. degree from the Massachusetts Institute of Technology.

William R. Lowry is an associate professor in the political sciences department at Washington University. He received a B.S. degree (1979) in business administration from Indiana University, an M.B.A degree (1983) from the University of Illinois—Chicago, and M.A. (1985) and Ph.D. (1988) degrees in political science from Stanford University. His research interests include political institutions and public policy with a particular focus on the environment and public lands. He has written extensively on politics and public commons. Dr. Lowry received his Ph.D. in political science from Stanford University.

Barry R. Noon is a professor at the Department of Fisheries and Wildlife Biology in Colorado State University, Fort Collins. Before joining the faculty of CSU, he was a research wildlife biologist and later a research ecologist with the U.S. Forest Service. He has held teaching positions at Humboldt State University in Arcata, California and Sienna College in New York. His fields of interests include conservation planning for threatened and endangered species, science-based management of public lands to conserve biological diversity, population dynamics and

viability analysis for at-risk species, and vertebrate demography and life history. He received his B.A. degree in biology from Princeton University and his Ph.D. degree in biology from the State University of New York in Albany.

Robert W. Sterner is a professor at and the current head of the Department of Ecology, Evolution, and Behavior at the University of Minnesota. Before joining the faculty at the University of Minnesota, he was a member of the faculty at the University of Texas in Arlington, Texas and was a postdoctoral fellow at the Institute for Limnology in Plon, Germany. His research interests are in the areas of limnology, plankton ecology, food webs, aquatic biogeochemistry, and nutrient dynamics. His research combines ecosystem science with population processes such as competition and predation. He received his B.S. degree in biology from the University of Illinois and his Ph.D. degree from the University of Minnesota.

Thayer Scudder is a professor at the Division of the Humanities and Social Sciences, California Institute of Technology, Pasadena, California. His research encompasses the fields of river basin development, forced relocation, and refugee reintegration in many areas around the world including Africa, India, Nepal, Jordan, Indonesia, Malaysia, the Philippines, Sri Lanka, and the United States. Dr. Scudder graduated cum laude in general studies from Harvard College in 1952 with a concentration in anthropology and biology. He received his Ph.D. degree in anthropology from Harvard University. After leaving Harvard, Dr. Scudder spent a year at the London School of Economics doing a postdoctorate in African Studies, Anthropology and Ecology. After positions with the Rhodes-Livingston Institute for Social Research in Northern Rhodesia 1956-1957 and again in 1962-1963, and a post at the American University in Cairo in 1961-1962, Dr. Scudder joined the faculty at CalTech.

National Research Council Staff

Jeffrey W. Jacobs is a senior program officer at the Water Science and Technology Board of the National Research Council. His research interests include organizational and policy arrangements for water resources planning, water resources science and policy relations, and river system management. He has studied these issues extensively in Southeast Asia and in the United States, and has conducted comparative research be-

tween water management issues in the United States and Southeast Asia. He received his B.S. degree from Texas A&M University, his M.A. degree from the University of California (Riverside) and his Ph.D. degree from the University of Colorado.

Ellen A. De Guzman is a research associate with the Water Science and Technology Board of the National Research Council. She has worked on a number of studies including Privatization of Water Services in the United States, Review of the USGS National Water Quality Assessment Program, and Drinking Water Contaminants (Phase II). She co-edits the WSTB newsletter, annual report, and manages the WSTB homepage. She received her B.A. degree from the University of the Philippines.

Jon Q. Sanders is a senior program assistant with the Water Science and Technology Board. He received his B.A. degree in anthropology from Trinity University. He is a member of the Society for Applied Anthropology and the American Indian Science and Engineering Society. Mr. Sanders has worked on a variety of projects at the WSTB ranging from desalination to Everglades restoration. He is coauthor of "Sitting Down at the Table: Mediation and Resolution of Water Conflicts" (2001). Jon's research interests include political ecology, Texas water issues, and environmental decision making.