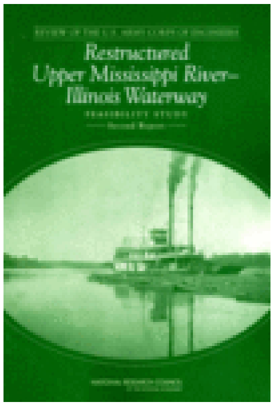

Review of the U.S. Army Corps of Engineers Restructured Upper Mississippi River-Illinois Waterway Feasibility Study: Second Report

Committee to Review the Corps of Engineers Restructured Upper Mississippi River-Illinois Waterway Feasibility Study, National Research Council

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REVIEW OF THE U.S. ARMY CORPS OF ENGINEERS

Restructured Upper Mississippi River–Illinois Waterway

FEASIBILITY STUDY

Second Report

Committee to Review the Corps of Engineers Restructured
Upper Mississippi River-Illinois Waterway Draft Feasibility Study

Water Science and Technology Board
Division on Earth and Life Studies

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COMMITTEE TO REVIEW THE CORPS OF ENGINEERS RESTRUCTURED UPPER MISSISSIPPI RIVER-ILLINOIS WATERWAY DRAFT FEASIBILITY STUDY[1]

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[1] The activities of the Committee to Review the Corps of Engineers Restructured Upper Mississippi River-Illinois Waterway Draft Feasibility Study are overseen and supported by the National Research Council's Water Science and Technology Board (lead) and the Transportation Research Board.

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Preface

> The Mississippi is well worth reading about. It is not a commonplace river, but on the contrary is in all ways remarkable.
>
> Mark Twain, *Life on the Mississippi*, 1863

As an ecological and economic resource of enormous size and inestimable value, the Upper Mississippi River remains as remarkable today as it was in Mark Twain's time. The Illinois Waterway is also extraordinary in its own way, beginning with the late nineteenth century engineering feat of reversing the Chicago River's direction of flow. Four other rivers were then interconnected to form a navigation channel that extends from Lake Michigan to the Mississippi River at Grafton, Illinois, thus creating a hydrologic connection between the Great Lakes and the Gulf of Mexico. Attempts to facilitate commercial navigation on these waters have occupied the federal government since the 1820s, growing ever more challenging as the number and severity of resource conflicts increased. However, this task became even more difficult in 2001 when the U.S. Army Corps of Engineers decided to simultaneously address navigation improvements and the ecological degradation that has accompanied Mississippi and Illinois River lock and dam construction and operations. This decision resulted in the Corps issuing its *Restructured Upper Mississippi-Illinois Waterway System Navigation Feasibility Study*, which proposed an integrated plan for navigation improvements and ecosystem restoration (the first interim report of the Corps' restructured study was issued in July 2002; USACE, 2002).

In March 2003, the Corps of Engineers requested that the National Research Council (NRC) convene a committee to review the restructured study. Our committee was formed in the summer of 2003 and met for the first time in September of that year. Our first report consisted of a review of the 2002 study and information gathered at our first meeting (September 2003), and was issued early in 2004 (NRC, 2004a). Our committee held three meetings after that first report was issued. A draft integrated feasibility report was published by the Corps on April 29, 2004 (USACE, 2004). This report presents the results of our committee's review of that feasibility

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report. Our committee is also scheduled to produce a third report in 2005.

It is important to note that both the Corps' study and this committee have immediate predecessors. In the late 1990s, the Corps was occupied with a major study of navigation improvements on these same waterways. That effort, however, was directed to a single purpose (navigation) and did not include an ecosystem restoration component. Just as the study was nearing completion, controversy erupted on several fronts. In response to public criticism, the Department of Defense requested the National Research Council to review the ongoing study. That committee completed its work in a single report issued early in 2001 (NRC, 2001). In response to that report and to other criticisms, the Chief of Engineers temporarily paused the navigation study until it could be replaced by the broader and more complex restructured study, which is discussed herein. Because of this history, we refer to the 2000-2001 NRC committee as the "Phase I" committee and to our present committee as the "Phase II" committee. Except for the Phase I committee chair (Lester Lave), this Phase II committee has no members that served on the Phase I committee.

The Phase I committee made several recommendations that were influential in the Corps' restructuring of the study. Other recommendations, however, were not acted on or were only partially considered. As the Phase II committee began its study, we carefully examined each of the Phase I recommendations and found none with which we disagreed. In fact, some Phase I findings and recommendations are repeated in this report. Readers of this report should be aware that this committee continues to support all of the recommendations in the Phase I report, whether mentioned here or not.

In preparing its second report, the Phase II committee met with and heard from a variety of interested parties in three public meetings. In St. Louis in December 2003, those guests were Richard Astrack of the Corps of Engineers (St. Louis); Michael Babcock of Kansas State University; John Chick of the Great Rivers Field Station (Brighton, Ill.); Michael Dyer of the U.S. Department of Transportation Volpe Center (Cambridge, Mass.); Commander Suzanne Engelbert of the U.S. Coast Guard (St. Louis); D. Demcey Johnson of the U.S. Department of Agriculture (Washington, D.C.); Bruce Scherr, Donald Frahm, and Kenneth Erickson of Sparks Companies, Inc. (Memphis, Tenn.); and Royce Wilken of Archer Daniels Midland (Decatur, Ill.). In Irvine, California, in February 2004, our guests included several Corps of Engineers staff. Kenneth Barr, Denny Lundberg, and Richard Manguno in particular helped update the committee on changes and progress within the feasibility study in an informative afternoon session. In Red Wing, Minnesota, in May 2004, our guests were John Beghin of Iowa State University; Mark Boerkrem of the Illinois Steward-

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ship Alliance (Rochester, Il.); and Dan McGuiness of Audubon (Woodbury, Minn.), as well as several Corps of Engineers staff, including Brigadier General Don T. Riley, Kenneth Barr, Denny Lundberg, and Richard Manguno. At all three meetings, these individuals gave their time generously and were patient in speaking with our committee and in responding to a wide variety of questions. The importance of their contributions to enhancing our understanding of the feasibility study and key management issues on the Upper Mississippi River-Illinois Waterway cannot be overstated, and we sincerely thank all of them for taking time from their busy schedules to assist us.

In negotiating a daunting stack of printed material, our review was facilitated by the lucid and comprehensive presentations by members of the Corps study team. These individuals include the study project manager Denny Lundberg, along with Kenneth Barr, Richard Manguno, Jeffrey Stamper, and many others. We are particularly grateful for a working relationship with the Corps that was uniformly helpful, professional, and open to candid exchange of views. For this, we greatly thank Brigadier General Don T. Riley, who set the tone for the entire relationship. We also thank Colonel Duane Gapinski, William Dawson, Richard Worthington, and the members of the Corps study team.

This report was reviewed in draft form by individuals chosen for their diverse perspectives 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 individuals for their review of this report: John C. Beghin, Iowa State University; Michael S. Bronzini, George Mason University; Kenneth L. Casavant, Washington State University; Stanley A. Changnon, University of Illinois, James R. Hanchey, State of Louisiana Department of Natural Resources; Rachel Muir, U.S. Geological Survey; Doug Plasencia, AMEC; Paul M. Schonfeld, University of Maryland; Jack A. Stanford, University of Montana; Frank H. Stillinger, Princeton University; and James L. Wescoat, Jr., University of Illinois.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Walter R. Lynn, Cornell University, who was appointed by the Division on Earth and Life Studies and by Charles E. Phelps, University of Rochester, who was appointed by

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the NRC's Report Review Committee. Drs. Lynn and Phelps were responsible for making certain that an independent examination of this report was carried out in accordance with 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 institution.

NRC committees are comprised of talented and busy scientists, engineers, and other experts. Given that the volunteers on our committee, like all NRC committee members, have "day jobs" and serve on these committees without compensation, it is remarkable how much time and attention each member has devoted to this study. Yet no matter how committed and energetic the committee members may be, much of the hard work of planning meetings, maintaining communications, and assembling, editing, and writing our reports falls upon the NRC staff officers assigned to the committee. In this case, Study Director Jeffrey Jacobs of the NRC Water Science and Technology Board has been extraordinarily effective in handling an unusually large workload on a compressed schedule. Jeff was ably backed up by Senior Staff Officer Joseph Morris of the NRC Transportation Research Board. Anita Hall of the Water Science and Technology Board helped arrange meeting logistics, travel, and many other duties. Florence Poillon provided excellent editorial assistance in the preparation of this report's final version. Finally, Stephen Parker, director of the Water Science and Technology Board, and Steve Godwin, director of the Transportation Research Board's Policy Division, provided steady overall guidance and input. We thank them all.

John J. Boland, Chair

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Executive Summary

This is the second of three reports from the National Research Council (NRC) Committee to Review the U.S. Army Corps of Engineers Restructured Upper Mississippi River-Illinois Waterway (UMR-IWW) Feasibility Study. The committee's initial report (NRC, 2004a) was primarily a review of a Corps of Engineers interim report (USACE, 2002). The following report represents a review of an updated and revised version of a study that was released by the Corps of Engineers in April, 2004 (USACE, 2004). It also contains comments on supplemental reports and other inputs, namely reports from the Sparks Companies, Inc. (of Memphis, Tenn.) on U.S. grain export forecasts (Sparks Companies, 2002) and from the U.S. Department of Transportation's Volpe National Transportation Systems Center (of Cambridge, Mass.) on nonstructural measures for waterway traffic management (Dyer et al., 2003), and the Corps of Engineers' Tow Cost Model. A third report from this committee is due in 2005. This committee's statement of task was to review key issues, data, assumptions, and areas of controversy within the feasibility study, which includes economic, environmental, engineering, and plan formulation considerations (the full statement of task is listed in Chapter 1). This executive summary addresses the topics of integrated river system planning, ecosystem restoration, managing waterway congestion, forecasting river traffic levels, and the Tow Cost Model. It concludes with a brief summary of the report's key points and recommendations.

INTEGRATED RIVER SYSTEM PLANNING

The Upper Mississippi River-Illinois Waterway system is a natural resource of enormous value to the nation. As the largest riverine system in the United States and the third-largest drainage basin in the world, it is an

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ecological resource of global significance. It provides an array of services to tens of millions of residents and visitors, including drinking water supply, boating, fishing (commercial and recreational), hunting, trapping, tourism, and commercial navigation. Communities, farmers, and tourists all use the river system's floodplains, which provide sites for settlement, rich soils, and abundant recreational opportunities. These floodplains also experience occasional floods, which entail both costs and benefits. The same flood that threatens levees that protect farm land or communities also increases spawning habitat for fish on un-leveed floodplains. Historical modifications of the river to enhance commercial navigation, and land use changes across the watershed resulting from agriculture, forestry, and urbanization, have fundamentally altered hydrology and habitat. Similarly, actions aimed at ecosystem restoration may affect commercial navigation and other sectors. Sound river management decisions should consider the many values the river system provides, as well as interactions between users. The challenge is to find a balanced program that promotes individual uses while increasing the aggregate value of the Upper Mississippi River and Illinois Waterway to the nation. To its credit, the Corps has creatively expanded its feasibility study over time in an effort to broadly consider these interdependent issues, while also recognizing that the agency has neither the authorities nor the resources to plan and manage all of these issues across the entire UMR-IWW. Nevertheless, many of these uses and sectors are inseparable, and changes or impacts in one sector often affect other sectors. Declines in the value of any of these sectors are of national-level concern. A comprehensive feasibility study will consider these types of interrelations to help manage the system accordingly, and the Corps is correctly attempting to consider some of these relations between sectors.

The Corps of Engineers operates under a large body of authorities, legislative acts, and congressional committee language. This body of directives has accumulated over time without the benefit of any overall strategy or framework. Consequently, new authorities or legislation may be inconsistent with existing directives to the Corps. In instances in which guiding legislation or authorities are contradictory or unclear, the Corps is placed in the position of having to choose which authority or act will be given precedence. Within the context of the UMR-IWW feasibility study and the operations of the navigation system, the Corps considers the 1930 Rivers and Harbors Act that authorized the 9-foot channel project for the Upper Mississippi River as the primary management authority. Although a legal analysis of this situation was beyond the scope of this report, the current situation clearly poses ambiguities for the Corps and confounds the agency's ability to manage the system in a way that maximizes its value to the nation. Although legislation subsequent to the 1930 Rivers and Harbors Act (e.g.,

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the Upper Mississippi River Management Act of 1986) has proposed broader objectives for river management, the 1930 authorization is assumed by the Corps and some others to be the overriding authority in managing the resources of the UMR-IWW system. This single-purpose authority represents a barrier to the Corps and other agencies in adequately integrating other system values and uses, especially restoring river ecology, in UMR-IWW management decisions. The Corps and other UMR-IWW stakeholders recognize the limitations that this single-purpose authority imposes on trying to manage the system's multiple resources. Consequently, in its feasibility study the Corps is seeking to add ecosystem restoration as an authorized UMR-IWW project purpose. This request is appropriate because it would enable the Corps to more holistically manage UMR-IWW resources in a way that better reflects today's multiple users and diverse values (fulfillment of this request could also help clarify authorization priorities). Yet the request in itself may be insufficient for managing resources and issues that go beyond navigation and ecology, namely floods.

The Corps' efforts to seek broader authority for planning and implementing projects on the UMR-IWW system are appropriate. The Corps should request a multiple-purpose planning and operations authority for the UMR-IWW, which would permit the agency to address flood management, navigation, and ecosystem restoration issues concurrently.

ECOSYSTEM RESTORATION

It should be emphasized that "restoration" of ecological structure, functions, and habitat in a system as large as the UMR-IWW is essentially unprecedented, and there is no perfect blueprint for restoration efforts on the UMR-IWW. Broad principles of large floodplain river science and management, as well as large river management experiences in the United States and around the world, may hold useful lessons for managing UMR-IWW resources (Europe's Rhine and Danube Rivers, for example, are sites of ongoing restoration activities). It is also necessary to understand the constraints that the existing navigation system places on ecosystem restoration, and to explore linkages between the two purposes in a search for mutually beneficial actions. Although there are opportunities for improvement in the study's ecosystem restoration component, the Corps has made good progress in this essentially unprecedented realm. Implementation of ecosystem restoration measures in the UMR-IWW will take place in a dynamic setting, with environmental and social changes that cannot be perfectly predicted, which suggests the necessity to manage adaptively. Part of "adap-

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tive management" entails monitoring the impacts of management actions and using this information in future decisions.

The Corps has made progress by broadening the feasibility study to include a wide range of ecological restoration options, which entail hundreds of possible "projects" that could be implemented within the river-floodplain ecosystem. Although all of these projects conceivably have merit and may contribute to restoration goals, the prioritization, constraints, and prospects for success of these individual projects could be better explained; at present, it is difficult to understand which projects are the most promising and which should be implemented first. Although a clearly defined path forward for "restoring" river ecology in the UMR-IWW does not exist, the feasibility study's approach to restoration could be clarified and its scientific basis strengthened by prioritizing actions that focus on restoring fluvial processes. Recovering some degree of these processes may at times affect structures, property, and human livelihoods; infringements upon these factors as part of ecological restoration must therefore be carefully considered. Linking proposed actions to larger, science-based themes and guiding principles for the ecosystem restoration component of the feasibility study, while representing implementation challenges of their own, would provide (1) a clear science-based framework for the feasibility study, (2) quantifiable metrics (e.g., flows, pool elevations, and acres inundated by floodwaters) for assessing progress toward restoration, and (3) a system for prioritizing management actions that have the best prospects for restoring ecological functions and processes. In moving to strengthen the scientific dimensions of the feasibility study and to explicitly incorporate adaptive management principles, the Corps should make full use of the federal-state Environmental Management Program (EMP). Established in 1986, EMP participants include the Corps, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, and the five Upper Mississippi River basin states. The EMP was established to promote ecosystem restoration projects on the Upper Mississippi River, and to promote data gathering and ecological research. The EMP represents one of the nation's best examples of a large river ecosystem monitoring program. Data collected and reports issued by the EMP should be an important part of the scientific basis for UMR-IWW management.

Since UMR-IWW ecology has important linkages with other sectors such as commercial navigation, recreational boating, and floodplain development, some future restoration measures may entail impacts on these other sectors. The menu of possible restoration measures is large. Some of those measures may entail only minimal disruptions to other sectors. Larger-scale measures, however, may well have noticeable impacts on recreation and commercial navigation. It is not clear when or where larger-

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scale ecosystem measures might be enacted, and decisions regarding such actions will include input and opinion from the Corps and other federal agencies, state resource agencies, stakeholder groups, and the public. Yet because many, if not most, important future UMR-IWW management actions will entail trade-offs between sectors, information about how various sectors might be affected (perhaps including preliminary quantification of effects) is essential to good decision making. The feasibility study would be improved by a more prominent acknowledgment of sectoral trade-offs within the system, as well as discussions of the implications of future management decisions for trade-offs between sectors.

The ecological dimensions of the study could be strengthened by focusing efforts on restoring system-level hydrology and by broadening efforts to reestablish connectivity between the floodplain and river channel (or increasing the number of acres that can receive floodwaters during high flows) in areas where these connections have been disrupted by flood management projects and where there is support for alternative approaches (including willing sellers of leveed lands). The feasibility study should also more explicitly acknowledge and explain the interconnections between different users within the UMR-IWW and explore some of the key trade-offs that are likely to be part of future UMR-IWW management decisions. The feasibility study should be based clearly and explicitly on adaptive management principles, which rest upon both strong stakeholder collaboration and adequately funded, sustained monitoring programs. Management actions and policies regarding UMR-IWW resources should clearly incorporate and build upon past and ongoing monitoring and science programs of the federal-state interagency Environmental Management Program.

MANAGING WATERWAY CONGESTION

The current system for managing congestion at locks on the UMR-IWW is largely a "first-come, first-served" system. The issue of alternative, nonstructural systems for managing waterway traffic has been a topic of considerable discussion, with some groups (including this committee in its first report and the "Phase I" committee) recommending implementation of more efficient management systems. To respond to calls for more efficient waterway traffic management systems, the Corps has considered a variety of nonstructural measures for managing waterway traffic congestion. Several promising traffic management strategies have not been adequately considered or evaluated in connection with the feasibility study, however, including combi-

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nations of real-time scheduling and lockage priority rules (as presented in several different papers, some of which were published by the Corps; see, for example, USACE, 1999), "slots trading" proposals, or congestion fees. Although there are signs that these and other potentially useful nonstructural measures are being considered or are under development, there is no guarantee that such measures will be vigorously pursued and implemented in the future. The near lack of any analysis of the viability of nonstructural measures for managing waterway traffic represents a considerable analytical gap within the feasibility study, because it is not clear how the benefits of lock extensions can be reliably estimated without first managing waterway traffic more efficiently within the existing system.

More efficient nonstructural measures for managing UMR-IWW traffic are needed regardless of whether lock extensions on the UMR-IWW system are constructed; if extensions are not constructed (or if it is decided to delay construction), more efficient management of the system will be necessary to improve operational efficiencies. For example, as part of the president's fiscal year 2004 budget background information, the executive-level Office of Management and Budget recommended that for inland waterways navigation projects, "The Corps should make greater efforts to reduce traffic congestion through scheduling and other demand-management approaches." If extensions are constructed, more efficient nonstructural measures will be necessary to alleviate the reduced shipping capacity of the system during construction. Without such nonstructural measures, construction may result in more temporary congestion than is necessary. In either case, the Corps and others may be missing an opportunity to immediately lower transportation delays and costs. Like efforts to "restore" river ecology, creating a useful nonstructural traffic management system on the UMR-IWW is not a simple matter. Progress on this front, however, should be guided by the same adaptive management principles being considered for ecosystem restoration: build on existing experience, knowledge, and approaches (for example, the U.S. Coast Guard has developed a "vessel traffic service" [VTS] system that may have possible applications to the UMR-IWW), implement thoughtful and deliberate initial steps (e.g., a small pilot project(s) could be useful), monitor results carefully, and make appropriate adjustments and changes through time.

Implementing some nonstructural measures for managing waterway congestion could decrease congestion, reduce shipping costs, and use the existing waterway more efficiently. Because the costs of implementing nonstructural measures are low, and because some have positive net benefits, implementation of these measures should be of the highest priority. A comprehensive evaluation of UMR-IWW waterway traffic management alternatives will identify and thoroughly evaluate all plau-

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sible measures. The failure to consider and evaluate the prospects of all potentially beneficial nonstructural measures for better managing waterway traffic undermines the feasibility study's conclusions and recommendations regarding proposed structural improvements.

FORECASTING RIVER TRAFFIC LEVELS

Forecasts of UMR-IWW traffic levels figure prominently in the consideration of lock extensions. Forecasts of long-term increases in towboat traffic on the waterway would strengthen the case for extending locks from 600 to 1200 feet, while forecasts of stable or declining levels of exports provide less support for extensions (and likely imply that extensions are not economically justified). The creation and application of credible forecasts represent key analytical challenges within the feasibility study, because locks have a design life of several decades and the accuracy of waterway traffic forecasts diminishes considerably after 5 to 10 years.

Current commercial shipments on the UMR-IWW consist of roughly 50 percent grain (corn, soybeans, and wheat) and roughly 50 percent other goods (construction materials, petroleum products, coal and coke, chemicals, and fertilizers). A set of forecasts of U.S. grain export futures was produced by Sparks Companies, Inc., of Memphis, Tennessee for use in the Corps study. Consistent with advice from the NRC Phase I committee's 2001 report, a range of forecasts (rather than a single forecast) was produced. Five forecasts were presented in the 2002 Sparks Companies report. One of those forecasts reflected a scenario of a slight decline in exports over time. The other four forecasts presented increasing levels of U.S. grain exports over time. Today, none of these forecasts can, of course, be either fully verified or discounted. One of these five forecasts may eventually turn out to have been correct, U.S. grain exports may exceed even the greatest forecast increase, or exports may decline even farther than the "steady-to-low-decline" scenario. A range of global supply and demand variables, or "drivers," will affect future levels of U.S. grain exports, including income levels and consumer preferences in China, grain production policies and output in Brazil, changes in water use and supply in grain-producing regions, and prospects for local, U.S. domestic grain processing. Credible forecasts of U.S. grain export levels will consider trends in these drivers. Notable trends in one or more of these drivers may strongly influence a grain export forecast.

The presence of uncertainty does not mean that all futures are equally likely. The future flows from the past, and in the absence of changes in important "drivers" that interrupt this flow, the near future will continue to

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be much like the recent past. Sound forecasts should begin with a careful examination of the most important drivers that have shaped past trends. They should then examine how these drivers are expected to change, and whether new drivers are likely to be introduced. Widely accepted data show that U.S. grain exports since 1980 have been relatively steady. Although future changes in global grain demand and supply drivers are likely, there are no overwhelming regional or global trends that clearly portend a marked departure from a 20-year trend of steady U.S. grain export levels. U.S. grain export levels may indeed increase in the future (as suggested in the scenarios in the Sparks Companies report and in those from the U.S. Department of Agriculture), but there are also several plausible changes in global drivers that could lead to declining exports. For example, population growth and declining water tables in China could contribute to increasing demand for U.S. grain to feed to livestock in China. On the other hand, increases in income that affect consumer preferences in China could support increased demand for U.S. meat exports to China, which would replace exports of feed grain. Increases in the amount of irrigated cropland in China, and attendant increases in Chinese grain production, could also dampen demand for U.S. grain. Similarly, changes in U.S. agricultural subsidies and policies could influence grain exports in either direction. For example, some legislative incentives could encourage increased grain production; other incentives could encourage increased ethanol production, which would tend to reduce grain exports. Increases or decreases in export levels will be driven by changes in these types of factors that influence supply and demand in global and domestic grain markets. Absent these types of changes, future levels of U.S. grain exports, at least in the near term, are likely to resemble levels of the present and the recent past.

It should also be remembered that non-grain freight on the UMR-IWW constitutes about 50 percent of movements on the waterway, which introduces additional uncertainty regarding the movement of commercial goods. The non-grain barge traffic forecasts within the feasibility study are based on only one scenario for future movements of each of seven key non-grain commodities, as opposed to the multiple scenarios presented for grain shipments. Each non-grain commodity group forecast was developed separately based on models constructed in the mid-1990s. Traffic levels of nearly all of the seven non-grain commodity groups are forecast to increase about 20 percent over a 50-year period. If additional non-grain scenarios that included the possibility of steady or decreasing traffic levels were presented, the result would be a more complete and balanced set of barge traffic scenarios.

Non-grain shipments on the UMR-IWW are roughly half of total commodity shipments. A more complete set of scenarios of UMR-IWW waterway traffic would thus, in addition to considering the pos-

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sibility of both increases and decreases in grain commodity shipments, consider possible increases and decreases in non-grain commodity shipments.

THE TOW COST MODEL

The Corps' Tow Cost Model, or TCM, was originally developed by the Corps of Engineers Ohio River Division to model coal shipments along the Ohio River. The TCM has subsequently been used in the feasibility study to model changes in grain and other commodity shipments on the UMR-IWW in response to changes in shipping costs. The Tow Cost Model, however, has limited relevance and value within the UMR-IWW feasibility study. In particular, the TCM assumes that changes in shipping rates do not result in any traffic moving off the waterway to alternate modes until rates reach a specified level, a point at which all traffic then moves off the waterway. Because of this behavioral assumption, under specific circumstances the TCM can produce an "upper bound" on benefits of lock extensions. It is the case, however, that users such as grain shippers often have a variety of alternatives for responding to changes in shipping rates that include local processing of grain, shipping grain via an alternate mode, shipping grain via an alternate route, or shipping grain to a different destination port. Similar choices are available to shippers of non-grain commodities. These possibilities, however, are not considered in the TCM. For this reason, the TCM cannot be used to accurately estimate the benefits of reducing congestion. Instead, it estimates an approximate upper bound on economic benefits. **The Tow Cost Model contains assumptions and functions that do not adequately reflect responses of shippers to changes in shipping costs. It therefore produces results that are of only marginal use in the feasibility study.**

SUMMARY

- An UMR-IWW feasibility study that integrates commercial navigation and ecological restoration plans represents an unprecedented analytical challenge, and the Corps of Engineers is to be credited for broadening the scope of this effort during its study. The Corps has especially made substantial progress on the study during the past three years. Despite these efforts, the study contains flaws serious enough to limit its credibility and value within the policymaking process.

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- Despite statements to the contrary, the commercial navigation and ecosystem restoration components of the study have proceeded essentially on separate tracks. There is little evidence that prominent and important trade-offs and interactions between these two sectors and other users on the UMR-IWW were carefully considered.
- There has been more attention devoted to considering nonstructural measures in the April 2004 draft feasibility study than in previous versions. The study still lacks adequate analysis in this realm, however, and some promising nonstructural approaches for managing waterway traffic appear not to have been considered at all. The failure to fully consider nonstructural measures precludes any statement about the desirability of structural measures.
- The approach to estimating the benefits of lock extensions, using scenarios and upper and lower bounds on benefit estimates, is a reasonable way to deal with the uncertainties that attend the long lifetimes of inland waterway infrastructure, but the scenarios of future waterway traffic levels remain problematic. On further consideration, the largest concerns focus on the single forecast of non-grain commodities, and the scenarios reflect a bias in the direction of future increases in exports.
- The Tow Cost Model used to estimate benefits of lock extensions can provide no more than an approximate upper bound on benefits. In an attempt to deal with the TCM's shortcomings, the Corps developed the "ESSENCE" model. This model incorporates a hypothetical demand curve to estimate benefits of proposed lock extensions, but the curve has no empirical foundation. The ESSENCE model is therefore incapable of producing any credible estimate of a lower bound of the benefits of lock extensions. Economic feasibility has therefore not been demonstrated for any of the navigation alternatives.
- Substantial effort has been devoted to designing an ecological restoration program, and the proposed restoration measures represent an impressive range and number of candidate actions. The assembly of these measures into restoration alternatives, however, is not adequately grounded in principles and theories of large river floodplain science and restoration. For example, evaluation of the candidate alternatives relies, in part, on metrics (e.g., "area affected") that are poorly correlated with ecological outcomes. The ranking of alternatives is therefore unpersuasive.
- The Corps' Preferred Plan, if carried out as described, provides for a program of incremental implementation, an excellent framework for comprehensive adaptive management. If the Corps is provided the resources—and if it commits to the needed data collection, improved modeling techniques, and evaluation—many of the flaws and omissions in its study can be corrected in the course of implementation by application of adaptive management principles.

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1
Introduction

This is the second report of a three-report series of a National Research Council (NRC) review of the U.S. Army Corps of Engineers Restructured Upper Mississippi River-Illinois Waterway (UMR-IWW) Feasibility Study. This ongoing Corps study has its origins in the late 1980s, when the Corps began to consider the feasibility of extending several locks on the lower portion of the Upper Mississippi River (see Figure 1-1). The lock and dam system was constructed in the 1930s, pursuant to the 1930 Rivers and Harbors Act that authorized the Corps to construct a 9-foot navigation channel. The original locks were 600 feet in length. Over the ensuing decades, towboats on the UMR-IWW became larger and pushed more barges. Many tows on the river today are roughly 1000 feet long, which requires barges to be decoupled in order to pass through the locks, then be subsequently recoupled as they continue transiting the system. These "double lockages" require additional time for tows to pass through UMR-IWW locks, and congestion at several locks on the lower portion of the Upper Mississippi River has prompted claims that double lockages are a key contributor to chronic delays. The Corps thus began studies regarding the benefits and costs of extending several of these locks to 1200 feet.

The Corps began its studies in the late 1980s with separate investigations on the Upper Mississippi and the Illinois Rivers. These investigations were combined into a single system study in 1993. The spatial and analytical scope of the study presented some unprecedented planning challenges to the Corps and impeded progress and prompt completion of the study.

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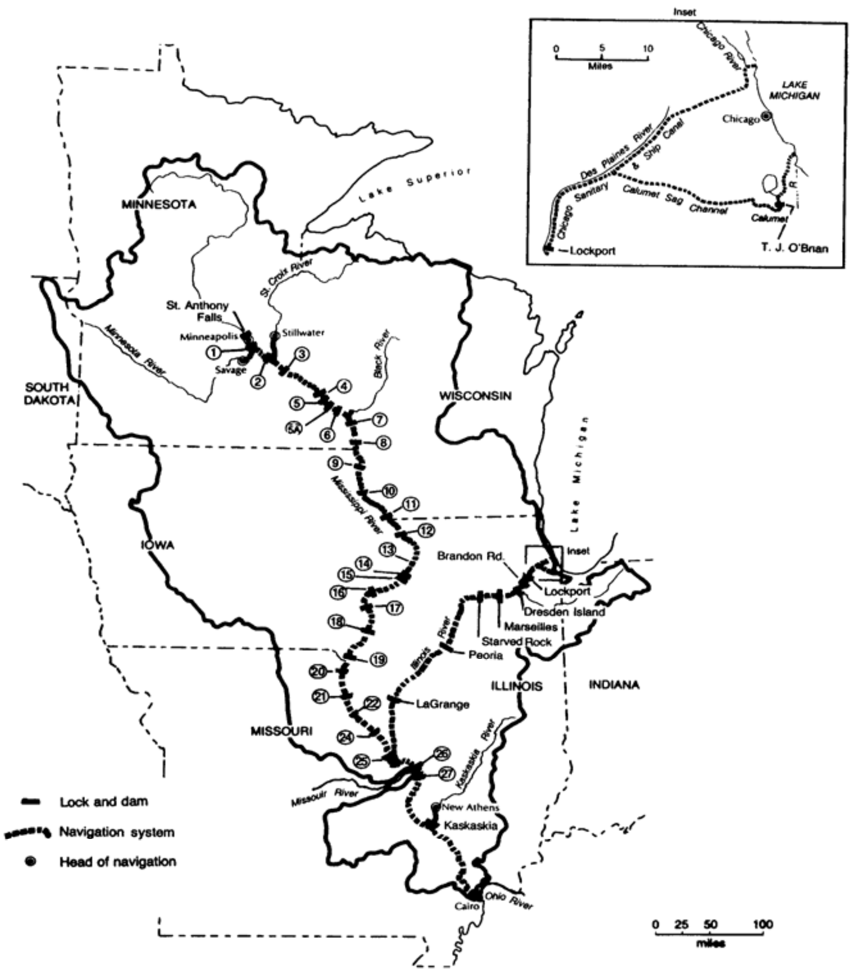

FIGURE 1-1 Locks and dams on the Upper Mississippi River-Illinois Waterway System. SOURCE: USGS, 1999.

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NRC REVIEW OF THE FEASIBILITY STUDY

In February 2000, the Department of Defense requested the National Research Council (NRC)[1] to convene a committee to review and to provide advice on the draft feasibility study. That committee completed its study and issued its report in early 2001 (NRC, 2001). In response to the NRC committee report, the Corps "restructured" its feasibility study and presented an updated version of the study in a July 2002 interim report (USACE, 2002). In March 2003, the Corps again asked the NRC to review its draft study. In contrast to the single report from previous "Phase I" NRC committee, this second ("Phase II") committee was requested to provide three reports: an initial report, a second more comprehensive report, and a final report. The initial report has been published (NRC, 2004a). This document is the committee's second report. A third and final report from this committee is scheduled for publication in 2005.

The statement of task for this committee's first two reports is the same (see below). The reports differ in that they comment on different versions of the feasibility study (which continues to evolve but is currently scheduled for completion in late 2004). The reports also differ in that the first report was to be a brief account of the committee's initial impressions of the feasibility study, with the second report representing a more comprehensive effort. This committee's third report will reflect upon several key river management issues on the UMR-IWW and will have a different statement of task. The statement of task for this second report from the Phase II committee is:

> The committee will review the Corps' Restructured Upper Mississippi River-Illinois Waterway System Navigation Feasibility Study. The committee will review several Corps documents that explain the analysis within the feasibility study, including the Corps' July 2002 Interim Report for the study. A key document for the committee's review will be a summary of the feasibility study that the Corps will provide to the committee before its first meeting. Since the 2001 NRC report, the nature of the Corps' feasibility study has broadened beyond the need for transportation improvements; the restructured feasibility study has taken a more holistic approach toward considering the relations between environment, navigation, and the floodplain. Given

[1]The NRC is the research arm of the National Academies. In addition to the NRC, the National Academies includes the Institute of Medicine, the National Academy of Engineering, and the National Academy of Sciences.

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> the emphasis on comprehensive river system planning in the restructured study, the committee will provide a comprehensive review of all aspects of the feasibility study, including economic evaluation, environmental analysis, design and engineering, and plan formulation focusing on key study assumptions.
>
> The committee will focus its review on the key study issues, assumptions, and areas of controversy. Although the committee will have discretion to determine appropriate topics for its review, it is expected that the review will include several topics that the prior committee commented upon and for which the Corps has proposed responses in the restructured study plan. These topics include the Corps' decision to replace the ESSENCE model with its Tow Cost Model; the appropriateness of the scenario-based forecasts of barge demand by commodity and how these varied scenarios will be incorporated into the subsequent analyses; how the restructured plan should incorporate the nonstructural alternatives (pricing, scheduling, etc.) into the feasibility analysis; the potential effectiveness of the proposed environmental restoration, its costs, and how the cost should be apportioned among the involved parties (federal, state, local, and private); and broad matters related to water resources systems planning and decision analysis.

This report does not give equal treatment to each issue mentioned in the statement of task but rather focuses on topics that are emphasized within the feasibility study—namely, the economics of commercial navigation (including economic models and forecasts of barge traffic) and ecosystem restoration.

Phase II Committee Activities

This committee's first report offered several findings and recommendations. Some of those findings and recommendations are revisited and elaborated on in this report, while others are not discussed here. Regardless of whether a finding or recommendation from the committee's first report is mentioned in this second report, the committee stands behind all of the findings and recommendations from its first report. Furthermore, the committee's first report contains important background information about the UMR-IWW system and the feasibility study that, in many cases, is not repeated here.

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That first report is thus a prelude to this second report and is essential background information for readers seeking a more complete understanding of this report. This second report reviews and evaluates the Corps' April 2004 draft feasibility study. That report from the Corps represents the most recent and comprehensive document in the feasibility study (the entire draft feasibility study and environmental impact statement can be found at *http://www2.mvr.usace.army.mil/umr-iwwsnsl,* accessed November 11, 2004). The 2004 draft report is more than 600 pages in length and contains 18 chapters on topics that focus on commercial navigation system improvements and ecosystem restoration measures. Additional details of the Corps feasibility study are listed later in this report, especially in Chapter 3.

Following completion of its first report, this committee held three meetings before issuing this second report. In St. Louis in December 2003, the committee spoke with several analysts and agricultural and navigation (and others) interest group representatives. These analysts included representatives from Sparks Companies, Inc. of Memphis, Tennessee and fromthe Volpe Transportation Center of Cambridge, Massachusetts. Both of these centers were enlisted by the Corps to produce reports for use in the feasibility study, and comments on those reports are included herein. At a meeting in Irvine, California, in February 2004, the committee met with several Corps of Engineers staff to discuss details and revisions to the feasibility study. Then in Red Wing, Minnesota, in May 2004, the committee spoke again with several Corps staff members, independent analysts, and representatives from environmental groups with interests in the UMR-IWW and the feasibility study. The meetings provided essential information about the feasibility study, its various inputs, and concerns of interest groups on all sides of the issue. In addition to meeting with these various groups at these three meetings, the committee also met in closed sessions in order to discuss guest speaker presentations and continue working on this report.

Following this introductory chapter, Chapter 2 describes the resources and uses of the Upper Mississippi River-Illinois Waterway system and some approaches and issues regarding multiple-purpose river management. Chapter 3 reviews details of the feasibility study and presents findings and recommendations. Like the Corps feasibility study, it includes sections on ecosystem restoration and commercial navigation. Chapter 4 is this report's final chapter, and it discusses the Corps' strategy for implementing the feasibility study.

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2
The Upper Mississippi River-Illinois Waterway System

This chapter provides background information relevant to the Corps of Engineers' UMR-IWW feasibility study. It explains the multiple uses and users of the UMR-IWW's vast resources, concepts and practices of integrated river management, and efforts at accommodating multiple uses in the management of the Upper Mississippi River 9-foot channel navigation project.

USES, VALUES, AND LINKAGES

The Upper Mississippi River-Illinois Waterway (UMR-IWW) system contains natural resources of immense value to the nation. Stretching roughly 2350 miles from its headwaters at Lake Itasca in northern Minnesota to the Gulf of Mexico, the Mississippi is the world's third-longest river (Robinson and Marks, 1994). The UMR-IWW supports a commercial navigation system that transports hundreds of millions of tons of commodities including grain, coal, chemicals, and petroleum products. According to the Corps' 2004 draft feasibility study (USACE, 2004), the Upper Mississippi River carried approximately 60 percent of the nation's corn exports and 45 percent of the nation's soybean exports. Environmental goods and services provided by the UMR-IWW's river-floodplain ecosystem include drinking water (the Mississippi River supplies drinking water to numerous cities and towns), hundreds of thousands of jobs related to recreation and tourism, and billions of dollars of revenues generated by residents and by visitors who travel to enjoy the region's natural and aesthetic resources. Many people use the river and its resources for boating, hunting, trapping, fishing, and sightseeing, and recreational and associated uses on

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the Upper Mississippi River generate revenue estimated at more than $1 billion per year (USACE, 1993). The UMR-IWW supports a rich array of ecosystems, species, and biodiversity, including the Upper Mississippi River National Fish and Wildlife Refuge, which was authorized by Congress in 1924 and extends from Wabasha, Minnesota, to Rock Island, Illinois. The refuge has the largest annual public use of any unit in the U.S. national wildlife refuge system (Holland-Bartels, 1992). Floodplains along the river provide sites for hundreds of communities, contain large agricultural areas, and serve as important highway and railroad corridors. Many areas in these floodplains are subject to flooding. Record floods occurred throughout the region in the summer of 1993, and the river system also experiences many smaller floods.

The Upper Mississippi River and Illinois Waterway systems have long supported this wide variety of human and economic uses, and different users of these systems have had various and changing effects on one another. Nineteenth century steamboats on the Upper Mississippi, for example, had few large impacts on river ecology; in fact, given the problems posed to the steamboats by snags, currents, and shifting sandbars during the steamboating era, the river system may have had more impacts on navigation activities rather than vice versa (Merrick, 2001, provides an account of mid-nineteenth century Upper Mississippi River steamboating). Urban and industrial activities and waste products have affected river ecology for decades. For example, concerns regarding the impacts of water pollution on the Upper Mississippi River's mussel fishery were expressed as early as 1898 (Smith, 1899; cited in Scarpino, 1985). Water quality continued to be a concern into the 1920s, when steadily declining mussel populations were attributed to not only aggressive harvesting practices, but also "stream pollution from the large cities along the rivers" (ibid.). There have been improvements in water quality since passage of the Federal Water Pollution Control Act Amendments of 1972 (amended in 1977 and known today as the Clean Water Act). Raw sewage, oil slicks, and phosphates are better controlled, but some aspects of water quality, such as sedimentation, have become a greater concern (Ellis, 1993). An important water quality issue today is fertilizer applications across the upper basin. These applications contribute to high flows of nutrients downstream in the Mississippi River, which contributes to hypoxia (an oxygen-deficient condition) in the Gulf of Mexico. These flows ultimately contribute to the creation of an area known as the "Dead Zone" in the Gulf of Mexico (Mitsch et al., 2001; Rabalais et al., 2002).

Commercial logging and increases in mechanized agriculture across the upper Midwest in the middle and late twentieth century changed the region's vegetative cover, which has had important implications for soil ero-

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sion and sedimentation rates, and related ecological processes, in UMR-IWW backwater areas. Recreational boating has long been popular across the region; boaters who use modern power watercraft enjoy benefits from the 9-foot channel project, because the project provides reliable and adequate draft depths for today's large and powerful vessels. Floods across the river system have a variety of beneficial ecological effects (e.g., Sparks, 1996), but those floods also cause economic and related damages to many floodplain communities. Flood control levees constructed along the river provide some degree of flood protection for communities and agricultural areas; these levees, however, restrict the ability of floodwaters to spread into floodplain areas and may thus increase peak flows downstream.

These examples of how activities in various economic and other sectors have affected various uses and purposes across the region also form a backdrop of environmental changes against which impacts of the construction and operation of the UMR-IWW system should be considered. Navigation improvement projects on the Upper Mississippi River in the later nineteenth and early twentieth centuries included a 4-1/2-foot channel project authorized by Congress in 1878 and a 6-foot channel project authorized by Congress in 1907. These projects focused on constricting the river channel and had noticeable, but limited, ecological effects. The 9-foot navigation project, authorized by Congress in 1930, represented a different approach to navigation improvements, however, because it created a series of navigation pools that fundamentally altered river hydrology (Anfinson, 1993). The 9-foot channel project was constructed and completed in the 1930s, and it has had important effects on river ecology that continue to affect the river ecosystem today. It should be pointed out, however, that the 9-foot channel is operated in a setting of many other environmental changes across the river basin, such as levee construction, floodplain and watershed agricultural practices, water quality changes, and population growth and urbanization, which complicates programs designed to help improve ecological conditions of the river system.

Sound water management strategies will acknowledge and consider these issues and connections. In the Upper Mississippi and Illinois River systems, finding management regimes that provide the greatest return to society entails not only consideration of these multiple linkages, but also collaboration between federal, state, and local agencies, numerous nongovernmental organizations, and citizens. These relationships and the management structures that have been developed to address them fall under the rubric of "integrated river management." The following section discusses the concept and previous embodiments of "integrated" river and water management, and how the concept relates to UMR-IWW system management.

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INTEGRATED RIVER MANAGEMENT: CONCEPTS AND APPLICATIONS

Many discussions and proposed actions within the broad scope of the UMR-IWW feasibility study have been presented in terms of an "integrated" management approach. Many groups with stakes in the feasibility study support "integration," and the Corps has proposed that "an integrated plan be approved as a framework for modifications and operational changes to the Upper Mississippi River and Illinois Waterway System" (USACE, 2004, p. xii). Within the context of river system planning or management, however, the term integration is not easily defined or implemented. A review of various definitions and applications of the term may be useful as the Corps, in collaboration with other federal and state agencies, proceeds with managing UMR-IWW navigation in the context of several other concerns and interests.

Integrated river resources management generally refers to both integration across space and to integration across sectors or purposes. For example, the river basin has long been viewed as the optimal unit for managing water and related resources. In the late nineteenth century, John Wesley Powell was an early advocate for the creation of administrative units to manage western U.S. water resources along watershed boundaries. President Theodore Roosevelt was a proponent of integrating water use sectors within waterway systems (see, for example, Roosevelt's 1908 report to the Inland Waterway Commission). The ideas of managing rivers and waterways comprehensively among sectors and across space have a rich tradition in the United States, and the Corps of Engineers and the U.S. federal government both have a long history of promoting water planning at the river basin scale. The Corps, for example, conducted "308" studies in the early twentieth century. These studies, authorized in 1927 by the U.S. Congress in House Document No. 308, consisted of reviews of river basin systems across the nation for the purposes of identifying prospective hydroelectric power and flood management projects.

The concept of integrated river or water management is complex, and it incorporates economic, engineering, social, and cultural considerations. The term "integrated" implies a process of seeking, recognizing, and establishing new linkages among various aspects of the system (Wescoat and White, 2003). The concept's broad and ambitious nature makes it difficult to clearly and concisely express (Biswas, 2004). Nevertheless, there have been notable and eloquent statements on this subject. For example, a panel of experts appointed by the United Nations (1958) interpreted integrated river basin development as "the orderly marshalling of water resources of river basins of multiple purposes to promote human welfare." In another

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seminal statement on the topic, U.S. water expert Gilbert White (1957) identified the three core components of integrated river basin development as (1) the multiple-purpose storage project—White cited the example of Hoover Dam and its multiple purposes of irrigation, water supply, hydroelectric power, flood control, and navigation; (2) the basin-wide program—this approach treats a river basin as a single hydrologic unit, and White identified the Tennessee Valley Authority (TVA) as the prototype; and (3) comprehensive regional development—White described this third component as "more difficult to describe than the other two, because it has not been fully realized in any part of the earth."

The twentieth century saw a variety of efforts aimed at integrated river and water management across the United States, the most durable and best-known of which is embodied by the TVA. Created during the Franklin Roosevelt administration in 1933, the TVA sought to promote rural development in the Tennessee River Valley and nearby regions through water resources development, especially hydroelectric power generation. The middle of the twentieth century saw the creation of several federal interagency river basin commissions, known as "FIARBC" programs. As part of the 1965 Water Resources Planning Act, the U.S. Congress established several "Title II" river basin commissions. There had been flaws in the basin interagency committee system, and the Title II commissions allowed greater roles for the states. The commissions, however, had their own set of limitations: they were generally unsuccessful at incorporating the environmental concerns of the era (Rieke and Kenney, 1997), they relied heavily upon consensus, and they had few powers beyond their roles in coordination. It is worth noting that in the middle of the twentieth century, the integrated river management concept—especially as embodied by the TVA model—was exported to many river basins in Africa, Asia, and Latin America.

Even though today the notion of strong federal centralized planning and management has lost some of its luster, the rationale for comprehensive water resources management across space and among sectors remains strong. A recent report from a National Research Council (NRC) committee that reviewed water withdrawal and salmon survival issues in the Columbia River, for example, recommended that "the State of Washington *and other basin jurisdictions* should convene a joint forum for documenting and discussing the environmental and other consequences of proposed water diversions . . ." (NRC, 2004b; emphasis added). Another recent NRC panel, which reviewed Corps of Engineers river and coastal system planning, also confirmed the importance of considering and planning for the spatial, hydrologic effects of individual Corps projects (NRC, 2004c). Also, an NRC committee that reviewed Missouri River ecosystem science recommended

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that adaptive management for the Missouri "be examined and conducted within a systems framework that considers the entire Missouri River ecosystem from headwaters to mouth, as well as the effects of tributary streams on the mainstem" (NRC, 2002).

The pursuit of integrated water management in the United States today might be characterized as one that continues to seek useful aspects of integrated planning, but with a more realistic (perhaps even skeptical in some instances) approach regarding the challenges of integrated river basin planning, especially across large systems with multiple jurisdictions like the UMR-IWW. Water resources management schemes for large U.S. river systems today tend to be more modest than those of an earlier era, with a decreased emphasis on primarily federally driven and centralized programs and an increasing emphasis on creating systems for basin-wide communication and federal-state cooperation (Rieke and Kenney, 1997). A decreasing faith in large-scale, "top-down" river basin-scale planning schemes has been accompanied by increasing interests in alternative programs, such as a variety of smaller-scale "watershed" planning initiatives across the nation. These watershed planning exercises generally emphasize decentralization of decision-making authority and vigorous public participation (Rieke and Kenney, 1997). In addition, a better appreciation of the limitations of linear systems planning for the "optimization" of river basins (Maass et al., 1962) has encouraged the development of approaches that recognize system complexity and surprises, and promote management actions that are to be monitored and adjusted accordingly. Many of these concepts are captured under the "adaptive management" rubric that the Corps and other federal water agencies are implementing at different scales in different regions, including the UMR-IWW. Nevertheless, despite the financial, institutional, technical, and social challenges posed by integrated river and water management, the rationale for comprehensive management of water and related sectors across space and time remains compelling. The experience with integrated water and river management in the United States and around the world is exceptionally broad, and caution must be used in trying to distill lessons from the diversity of settings in which it has been applied. With this caveat in mind, some of those lessons that may be useful as the Corps proceeds with its feasibility study include the following:

1. there are important linkages across water-related sectors and across space in watersheds and river basin systems;

2. institutional frameworks and policy regimes must recognize and respect these linkages and trade-offs if the various sectors of commerce and ecology are to be managed in a balanced way;

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3. recognition of the importance of these linkages and trade-offs is widespread, as evidenced by numerous and continuing attempts at managing across river basins and watersheds in the United States and around the world;
4. no two river systems are the same (White, 1957), and an ideal prototype for integrated water or river management has not yet been developed;
5. sound and balanced water resources management across sectors and across space requires collaboration among agencies, nongovernmental bodies, and citizens; and
6. to be effective, policies and organizations aimed at integrated water management must be flexible and adaptive in order to gain knowledge of economic, environmental, and related systems, and to adjust to changing conditions.

The Corps is conducting its UMR-IWW feasibility study in a setting in which the concept of integration is widely viewed as useful, but in which definitions of the concept are diffuse and continue to evolve. The following section examines more specific issues that may merit consideration in promoting integrated planning and management of the Upper Mississippi and Illinois River system.

INTEGRATED MANAGEMENT OF THE UPPER MISSISSIPPI RIVER-ILLINOIS WATERWAY

The complexities in a study of Upper Mississippi River and Illinois Waterway shipping and the navigation industry represent analytical challenges to the Corps because of the vast extent of areas affected by this system, and because of the various economic sectors related to the system. In spatial terms, a comprehensive study should consider hydrologic linkages consistent with the theme of integrated water management. However, grain exports from the upper Midwest compete in the global marketplace, and this market is affected by factors such as income and consumer preferences in China and by government investment in waterway transport systems in Brazil. Price, supply, and demand features of grain markets around the world should be considered in integrated management of the UMR-IWW. From a sectoral perspective, a variety of issues are relevant and could be considered in managing UMR-IWW resources, including U.S. agricultural policies and grain production in the upper Midwest, fishing and boating on the Upper Mississippi River, flood and floodplain management, land use practices across the watershed, and water quality in the Gulf of Mexico. Thus, not only do integrated management of the UMR-IWW and the Corps' feasibility study

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pose considerable analytical challenges (e.g., spatial grain modeling, ecosystem science), the Corps must also establish sufficient and reasonable bounds for the spatial extent and the breadth of issues considered in the study.

Integrating river management decisions across an area the size of the Mississippi River basin and its vast number of states and water management organizations represents a daunting task. Nevertheless, failure to address key water quality and quantity relationships adequately in a basin-wide context may contribute to excessive resource degradation and other problems. The issue of nutrient fluxes and eutrophication provides one example. The Mississippi River transports a substantial amount of nitrogen to the Gulf of Mexico, an amount that has increased nearly threefold since 1970 (Goolsby et al., 1999). The large amounts of nitrogen transported to the Gulf of Mexico have resulted in eutrophic conditions in the northern Gulf of Mexico, with hypoxic conditions occurring periodically over a widespread area (hypoxia is a condition in which dissolved oxygen concentrations are less than 2 mg/L, which most aerobic forms of aquatic life cannot tolerate for extended periods) (Mitsch et al., 2001; Rabalais et al., 2002). The severity of this problem in the Gulf of Mexico has led to hypoxia-reduction strategies becoming a national-level priority (NRC, 2000). Scientists have noted the important biogeochemical roles that wetlands historically played in the Upper Mississippi River basin and some of these scientists have proposed wetland restoration in the basin as a means to increase the removal of nitrogen from river water by denitrification (Mitsch et al., 2001). Proposed restoration efforts within the feasibility study thus have important implications for managing water and related resources across the entire basin and into the Gulf of Mexico. These types of spatial and interdisciplinary linkages should be considered within the context of an integrated UMR-IWW management program.

In addition, long-term environmental changes may affect the UMR-IWW region. For example, some climate records indicate that rainfall, runoff, and flood frequencies and durations have been increasing over the past several decades in several portions of the basin (e.g., the Illinois River; see Singh and Ramamurthy, 1990). At the same time, some global climate system models suggest that any increased precipitation associated with global warming will occur during the winter, with summer rainfall remaining roughly the same (Wuebbles and Hayhoe, 2004). Geologic evidence shows that very large floods were part of past climate conditions across the Upper Mississippi River basin. Sediment cores taken from the bed of the Mississippi River and in the Gulf of Mexico, for example, record several episodes of Mississippi River floods. Some of these floods had flows equivalent to what are today regarded as 500-year or greater floods, but that recurred much more frequently in the geologic past (the most recent occurring

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around 1000 B.C. and from about A.D. 1250 to 1450; Brown et al., 1999; Knox, 1993). These episodes were associated with increases in mean annual regional temperatures of only 1-2° C and by changes in mean annual regional precipitation of 10 to 20 percent (Knox, 1993), which are within some projected twenty-first century climate change projections for the region (e.g., Wuebbles and Hayhoe, 2004). Increases in flood frequencies, stages, or durations may strengthen the case for reconnecting rivers and their floodplains to better convey floods and reduce damages.

The focus of the Corps' study is the entire lock and dam system of the Upper Mississippi River-Illinois Waterway. The study was originally conceived as two separate studies, but in the early 1990s the Corps merged them into a single study. The study originally emphasized the navigation system and economic and commercial considerations (e.g., shipping rates, demand for waterway traffic, grain exports). Over time, however, the Corps has broadened the study to include ecological considerations, first of the river channel itself, and then the floodplain. Many of the Corps' analytical efforts within the study are unprecedented, and the agency—to its credit—has shown a willingness to expand and experiment with the boundaries of issues considered in the spirit of creating a more "integrated" and informative study.

Given that the concept of integrated river system management contains some degree of abstractness, there is no clear criterion by which the Corps' study can be objectively considered to be integrated. There are, however, varying degrees of spatial integration relating to issues considered within the study. A study of the entire lock and dam system, for example, is on a broader scale than a study of only those locks that experience waterway traffic congestion. Moreover, different components of the study likely require different degrees of integration. For example, development of a spatial price model for grain exports from the Upper Mississippi region should consider trends in global grain demand and supply. The consideration of flood risks and water quality issues, both of which extend downstream to the Gulf of Mexico, requires evaluation on a regional scale. Models of fish passage, or the effects of towboat passages on river ecology, are linked to smaller, local-scale phenomena.

The Upper Mississippi River-Illinois Waterway Feasibility Study

As mentioned, the Corps has expanded the scope of the feasibility study since the early 1990s, broadening it from a focus on the navigation system to more fully consider other sectors—especially river ecology and measures designed to improve ecosystem productivity. The study thus currently contains

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two distinct components, commercial navigation and restoration (of river ecology). Much of this broadening occurred in the year from July 2003 to June 2004, and the Corps demonstrated a good deal of creative thinking in doing so.

The navigation and river ecology components of the study have proceeded largely on separate tracks. The navigation component has generally proceeded on the assumption that the length of the commercial navigation seasons and channel depth (minimum of 9 feet) would remain unchanged, with ecosystem restoration projects being developed subject to these constraints. This approach, however, essentially places navigation in a superior position to other uses and does not fully reflect the reality and importance of interconnections between navigation and other sectors (and the values of those sectors) to the Upper Mississippi-Illinois system. Navigation plays an important role in the UMR-IWW and in the regional economy, but operation of the navigation system, including the system of navigation pools and the movement of towboats, affects other sectors that are also of great value to people and economies in the region and across the nation. The linkages between navigation and these other sectors are undeniable, and sound management of the UMR-IWW system will seek to minimize negative impacts to any of them. The challenge on the UMR-IWW is to find a balanced management program that maximizes the collective value of the resources of the UMR-IWW to the nation. The challenge of integrating socioeconomic and ecological concerns is tremendous, as reflected in a recent volume on global water management: "To arrive at truly integrated water management no aspect has been more difficult than the joint evaluation of social and environmental consequences" (Wescoat and White, 2003).

A well-integrated feasibility study would recognize these types of economic and ecological linkages and would consider navigation system management options in terms of their implications for other sectors. Navigation system management options would thus not only be considered in terms of direct economic costs and benefits to the commercial shipping sector, but would also recognize that operation of the navigation project has implications for river ecology and may thus entail "costs" to ecology and related sectors, such as ecotourism. A well-integrated study would, for example, consider a broad range of potential trade-offs between commercial navigation, river ecology, and other sectors such as recreational boating and floodplain management. Examples include shortening the commercial shipping season (which could be on various pools or on segments of the channel) while experimental drawdowns are conducted; allowing channel depths of less than 9 feet for a given period and loading tows lighter during that period; and considering how increasing the amount of land in floodways (through voluntary buy-outs) might affect commercial navigation.

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Legislation and Authorizations

The Corps of Engineers operates under a large body of authorities, legislative acts, and congressional committee language. This body of directives has accumulated over time without the benefit of any overall strategy or framework. Consequently, new authorities or legislation may be inconsistent with existing directives to the Corps. In instances in which guiding legislation or authorities are not clear or are contradictory, the Corps is placed in the position of having to choose which authority or act will be given precedence. Within the context of the UMR-IWW feasibility study and the operations of the navigation system, the 1930 Rivers and Harbors Act that authorized the 9-foot channel project for the Upper Mississippi River has been considered the primary authority. Although a legal analysis of this situation was beyond the scope of this report, the current situation poses ambiguities for the Corps and confounds the agency's ability to manage the system in a way that maximizes its value to the nation. Legislation subsequent to the 1930 Rivers and Harbors Act (e.g., the Upper Mississippi River Management Act of 1986) has proposed broader objectives for river management; nevertheless, the 9-foot channel authorization of 1930 remains the overriding authority in managing the resources of the UMR-IWW system. This single-purpose authority represents a barrier to the Corps and other agencies in adequately addressing other system values and uses, especially restoring river ecology. Many stakeholders within the UMR-IWW system with interests in the feasibility study support the notion of a broader management authority. The feasibility study explains this as follows:

> The stakeholders of the UMR system have expressed their desire to seek a balance between the economic, ecological, and social conditions to ensure the waterway system continues to be a nationally treasured ecological resource as well as an efficient national transportation system. It is proposed that an integrated plan be approved as a framework for modifications and operational changes to the Upper Mississippi River and Illinois Waterway System to provide for navigation efficiency and environmental sustainability, *and to add ecosystem restoration as an authorized project purpose*. The integrated plan will provide better focus and flexibility to adaptively manage the operation and maintenance of the system for both navigation and the environment. (USACE, 2004, p. xii, emphasis added)

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If the Corps of Engineers is to manage the multiple resources of the UMR-IWW in a balanced and integrated fashion, it must have the authority to do so. Without additional and broader authority from the U.S. Congress, the Corps will be hindered both in its ability to fully integrate navigation, ecology, and other appropriate considerations in the UMR-IWW feasibility study and in its efforts at integrated, balanced management of the UMR-IWW system. **The Corps' efforts to seek broader authority for planning and implementing projects on the UMR-IWW system are appropriate. The Corps should request a multiple-purpose planning and operations authority for the UMR-IWW, which would permit the agency to address flood management, navigation, and ecosystem restoration issues concurrently.**

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3
Technical Issues

The Corps of Engineers' UMR-IWW navigation feasibility study considers a large number of issues as they affect UMR-IWW system management. The Corps' study is broadly divided into two main topical areas: ecosystem restoration and proposed navigation improvements. This chapter reflects that organization, as it first reviews technical issues related to the ecosystem portion of the study, then reviews technical issues within the navigation component of the feasibility study.

ECOSYSTEM RESTORATION

Ecological Issues and Proposed Actions in the Feasibility Study

Over the past several years, the feasibility study's initial focus on Upper Mississippi River-Illinois Waterway commercial navigation issues has been broadened considerably. The Corps' 2004 draft study identified possible ecosystem restoration measures that included water level management, reconnections of river channel and floodplain, and prospects for enhancing fish passage past individual dams and through the river basin. The Corps deserves no small credit for proactively and appropriately broadening the scope of the study to better reflect the multiple values, purposes, and relationships within the UMR-IWW. The ecological portion of the feasibility study, however, contains flaws that inhibit the study's usefulness as a decision-making guide. Examples include a limited degree of integrating the implications of restoration alternatives with other, related system uses; limited emphasis on the importance of ecological processes in restoration; and a lack of clarity regarding project implementation, monitoring, and adaptive management.

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The following section explains and comments on the broad features of the feasibility study's plans for river restoration. Before that discussion, it is appropriate to first consider the literature on large floodplain river science and restoration.

Large Floodplain River Science and Restoration

There is near-unanimous opinion that UMR-IWW system management should proceed according to the best scientific knowledge available. This is especially important in the realm of ecosystem restoration because this field is relatively young and restoration actions are conducted in highly complex and dynamic systems. The Corps and other actors in the UMR-IWW will thus necessarily have to learn and adjust ecosystem restoration measures through time, and it is crucial that learning and adjustments proceed in accord with science-based principles. As the Corps proceeds with ecosystem restoration efforts, it should stay abreast of the literature in the field of "river science," which includes a strong focus on the roles of ecosystem dynamics in sustaining and promoting ecosystem processes and productivity (e.g., Bayley, 1995; Church et al., 1995; Junk et al., 1989; Koel and Sparks; NRC, 2002; Sparks, 1995; Sparks et al., 1998). It is worth noting that the federal-state Environmental Management Program (EMP) for the Upper Mississippi River, sponsored by the Corps, has produced a large body of scientific reports that have made notable contributions to the river science field.

At a 1994 conference held on the Upper Mississippi River in La Crosse, Wisconsin, several internationally recognized scientists synthesized the guiding principles of floodplain river ecology. These principles have held up well in the years following their formulation, and they should be used to help guide river restoration programs. They are especially applicable to the Corps' restoration program because they were developed from knowledge and experiences in large floodplain river systems such as the UMR-IWW:

> Ecological research and experience from a wide variety of large floodplain rivers indicates that the following principles for river management should have broad applicability:
>
> - River form and condition is a function of the totality of many actions and processes that occur in the basins, stream network, and floodplain.
> - The degree of connectivity between the main channel and its floodplain is a primary structural attribute of river ecological integrity.

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> - The annual flood pulse, channel-forming floods, and infrequent droughts are major driving factors in floodplain river ecosystems.
> - Rivers and their fauna are very resilient and measures to improve or rehabilitate them, if taken before critical levels are reached, can produce rapid positive responses in the system.
> - Ecosystem reaction to stress is often expressed catastrophically through critical breakpoints that only can be determined retroactively. That a breakdown in a system is likely can be anticipated, but foretelling the actual time when it will occur is far more difficult. (Church et al., 1995)

The Corps has recognized the primacy of fluvial and ecological processes in ecosystem well-being and in restoration strategies. The Corps convened an Environmental Science Panel in 2003 to provide input into the feasibility study process. That panel noted:

> With neither an ecosystem perspective nor an understanding of natural river function, there is a danger that such management actions will become a disjointed series of expensive engineering fixes in discrete managed areas. Inattention to how the original ecosystem functioned as a whole makes selective rehabilitation speculative, unlikely to achieve widespread success, and unlikely to be sustainable. It is therefore critical that restoration actions be planned and implemented with a fairly complete knowledge of key riverine and ecological processes, so that restoration and management actions can be selected to capitalize on that knowledge. (Lubinski and Barko, 2003)

River ecologists view rivers and floodplains as single systems because there are important exchanges of water, sediments, nutrients, and organisms between them that are fundamental to ecological well-being and productivity. On the UMR-IWW, the river-floodplain system has become increasingly "disconnected" through the construction of levees and other flood control structures. This disconnection is system-wide, but it increases as one moves downstream on the Upper Mississippi River. In the southern portion of the Upper Mississippi River, it is estimated that roughly 50 percent of the approximately 1,006,000 floodplain acres are behind levees (Delaney and Craig, 1997).

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The construction and operations of the dam and navigation pool system have also had stabilizing effects on UMR-IWW ecology (USGS, 1999). The system of dams and navigation pools, while important for providing a reliable commercial navigation channel, has reduced the natural hydrologic cycle of (spring) flooding and (summer and fall) drawdown in the UMR-IWW. This cycle is important for, among other things, maintaining habitat and water quality in riparian wetlands and backwaters of the UMR-IWW. In other places, unnaturally rapid fluctuations in summer water levels adversely affect moist soil vegetation and aquatic plants (Ahn et al., 2004). U.S. Geological Survey scientists working within the federal EMP explained these changes as follows:

> A growing body of evidence indicates that physical (geomorphic) processes and features control the biological structure and diversity of large floodplain rivers, particularly at large spatial scales. Scientists generally agree that the ecological diversity and integrity of large floodplain rivers are maintained by fluvial dynamics (annual flood pulses and channel-forming floods) and river-floodplain connectivity. Anything that tends to suppress the natural flood regime or constrain channel migration will disrupt these interactive pathways and lead to reduced ecological diversity and integrity. (Delaney and Craig, 1997)

The field of river science and restoration, and findings generated within the federal Environmental Management Program, point to the importance of fluvial processes in maintaining and restoring ecological productivity and diversity in large river floodplain systems such as the UMR-IWW. These findings prompted this committee to recommend in its first report that "priority should be given to restoration projects that aim to restore natural processes" (NRC, 2004a). Scientifically sound restoration within the feasibility study will thus focus on (1) reconnections of the river channel with its floodplain and (2) restoring some degree of the pre-settlement hydrologic regime. Box 3-1 provides specific examples of types of changes that could be used to promote these processes.

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Box 3-1
Restoring UMR-IWW Aquatic Ecosystems

The term "restoration" is frequently used to describe efforts designed to improve the overall social value of ecological habitat. A universally accepted definition of this term does not exist, and there are often differences of opinion regarding the state that constitutes a "restored" ecosystem. Nevertheless, many measures could be implemented in the UMR-IWW to help improve ecosystem productivity and the overall social value of ecosystem habitat. These options include the following:

1. Exposing mud flats to low, stable water levels during the summer growing season to promote growth of vegetation, with water levels drawn down late enough in the season to exclude colonization by willows and cottonwoods that would eventually shade out more diverse stands of vegetation.
2. Exposing sand islands during the summer nesting season where federally-endangered least terns and piping plovers (and other species) can nest free from land predators. Unnatural summer water-level fluctuations that drown the nests or connect the islands to land should be avoided.
3. Allowing a spring flood every one to three years to provide aquatic organisms access to spawning and nursery areas in expanded floodplain lakes and on the floodplains themselves. The floods should last at least six weeks, with a gradual recession (i.e., few reversals or "spikes") to avoid stranding fish eggs and larvae.
4. Providing accessible wintering areas for fish where water levels will not drop suddenly, water will not freeze to the river bed, current velocities are low, water temperatures remain at least 2-4° C, and dissolved oxygen concentrations remain above 3 mg/L.

Feasibility Study Goals, Alternatives, and Evaluation Metrics

Establishing Goals and Ranking Alternatives

Proposed ecosystem improvements within the feasibility study are framed by a "vision statement" (USACE, 2004, p. 159), which describes an effort "*to seek the long-term sustainability of the economic uses and ecological integrity of the Upper Mississippi River System*." The feasibility study recognizes this primary goal and lists a host of subsidiary "systemic ecosystem goals."

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These second-tier goals reflect the content of material presented in a 1994 paper on ecosystem management (goals 1-4 below; Grumbine, 1994) and a 2000 report from the Upper Mississippi River Conservation Commission (goals 5-13 below; UMRCC, 2000). The second-tier goals are listed in the Corps feasibility report as follows:

1. Maintain viable populations.
2. Represent all native ecosystem types across their natural range of variation.
3. Restore and maintain evolutionary and ecological processes.
4. Integrate human use and occupancy within these constraints.
5. Improve water quality for all uses.
6. Reduce erosion and sediment impacts.
7. Restore natural floodplain.
8. Restore natural hydrology.
9. Increase backwater connectivity with main channel.
10. Increase side channel, island, shoal, and sandbar habitat.
11. Minimize or eliminate dredging impacts.
12. Sever pathways for exotic species' introduction or dispersal.
13. Improve native fish passage at dams.

After defining the vision statement and this second tier of 13 goals, the feasibility study provides a long list of ecological considerations and possible "projects," including island building, fish passage, floodplain restoration, water-level management, backwater and side channel restoration, wing dam or dike alteration, island protection, shoreline protection, topographic diversity, and dam point control. These various measures are then grouped into five different alternatives, listed as A through E. A "virtual reference" condition is presented and described as "the characteristics of a system least impaired by human activities and . . . used to define attainable biological or habitat conditions." Alternative A represents a "no-action" scenario (essentially maintenance of status quo activities and expenditures), and alternatives B, C, D, and E represent increasing levels of expenditures with corresponding increases in ecological "diversity" (the virtual reference state lies beyond alternative E). Alternative E is explained as "restoration to include most environmental objectives that could be accomplished in the context of the navigation project" (USACE, 2004, p. 171). Levels of expenditures (over a 50-year period in 2003 dollars) range from roughly $1.7 billion for alternative B to roughly $8.4 billion for alternative E (USACE, 2004, p. 185). Accordingly, alternatives B through E generally entail increasing numbers of proposed projects (e.g., alternative B would entail approximately 40 "floodplain restoration" projects, and alternative E would entail about 75 such projects).

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The study (in Chapter 12) compares the different alternatives using a three-step evaluation process: (1) compare and rank alternatives using key evaluation criteria (e.g., environmental benefits, efficiency); (2) refine the alternative ranking with the remaining criteria (e.g., regional economic development, other social effects); and (3) identify other criteria, implementation considerations, or technical information not included in the evaluation scoresheet and process (including information provided by stakeholders). Under step 1, "three evaluation criteria were identified as being best suited to select the most appropriate ecosystem plan." These were "contribution to planning objectives," "environmental quality" (based upon criteria of "completeness" and "diversity"), and "efficiency of the alternative in addressing ecosystem needs." The third criterion was proposed as part of the analysis of National Ecosystem Restoration (NER) benefits and was further described as a cost-effectiveness measure, defined as the ratio of project cost to acres of project "influence." Chapter 14 of the study compares the final alternatives and selects the preferred alternative. In commenting on the alternatives, the study rejects alternatives B and C because "they do not contain all the tools and measures necessary to address restoration of key ecological processes and ecological diversity" (USACE, 2004, p. 508). Regarding alternatives D and E, the study concluded that "based on cost effectiveness, likelihood of successful implementation and reasonable estimate of potential cost shared floodplain restoration opportunities; Alternative D* is identified as the preferred ecosystem restoration measure" (p. 508).[1]

Evaluation Metrics and Terminology

The ecosystem portions of the study contain and explain many scientific concepts, but they are often presented without a clear explanation of why they are important, how they are to be measured and implemented, and how they relate to other concepts within the study. Terms such as "robustness," "risk," "ecological risk assessment," "environmental benefits," "adaptive mitigation," "adaptive management," and "virtual reference" are referred to throughout the study. Although such concepts are important and may be relevant, the study usually does not fully and consistently explain the relevance of such concepts, how they are to be measured, and how they fit into overall program implementation and operations.

[1] Alternative D was modified, as a result of stakeholder input and discussion, to produce a similar alternative D*. Key aspects of alternative D* are its estimated total cost of $5,182,800,000, its estimated ability to achieve eight of nine environmental objectives listed in the 2000 UMRCC report, and its estimated ability to "restore" ecology in "relation to existing condition" (USACE, 2004, p. 447).

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The components of the ecosystem part of the study, or individual restoration projects, are not clearly framed or bound together by ecosystem science principles. There are efforts to tie them back to the first- and second-tier criteria (USACE, 2004, pp. 449-450), but these efforts are weakened by the lack of clearly defined and measurable criteria. For example, goals 7 and 8 are described as "restore natural floodplain" and "restore natural hydrology." The meanings of these terms are not clearly defined, and no measurable indices are offered that could be used to determine whether progress is being made toward a goal or to explain exactly what goal (in quantifiable and measurable terms) is being pursued and expected. For both goals it is important to clarify what is meant by "natural"; if it means "pre-settlement conditions," there is no consideration within the study of returning the river and floodplain ecosystem to a state that existed centuries ago. In another example, in comparing alternatives A-E, the study suggests that most of the alternatives satisfy the second-tier goals adopted from the UMRCC (2000) report, but the feasibility study does not clearly explain how it was determined that a given alternative did or did not meet one or more of these criteria. Alternative D* was identified as the preferred ecosystem restoration plan because, in part, it is estimated that it will achieve eight of the nine second-tier goals (as identified in UMRCC, 2000). However, since these goals are all expressed in qualitative terms (e.g., restore natural floodplain, restore natural hydrology), it is not clear what unit(s) of measurement will be used or what threshold value(s) must be attained for a given measure to achieve its objective.

River science theories and principles could be better incorporated within the process of evaluating, ex ante, the potential effects of restoration actions. The key metric for ranking and comparing restoration projects throughout the study relates to the (potential) area affected in an individual restoration effort, expressed as the "project footprint," in most instances with units of either acres or structures. The areal extent of restoration efforts may be important in cases such as island construction projects, but this single metric is not well correlated with ecosystem function across the wide diversity of restoration projects being considered and is, thus, an inadequate metric for ranking and comparing all restoration measures. A more comprehensive, science-based system for prioritizing restoration actions would explicitly consider a broader variety of metrics, emphasize those that focus on ecosystem processes and functions, and consider restoration actions within the broader context of the entire UMR-IWW system. Clearly, the science and practice of system-level ecological restoration are in their infancy, and in many cases it is not possible to formulate and evaluate alternatives to the same degree of precision possible when economic development is the single objective. However, the feasibility study attempts to utilize traditional Corps planning princi-

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ples of alternatives evaluation that are not necessarily well suited to ecological restoration measures and objectives. This does not mean that no restoration measures should be attempted, but rather argues for the importance of a phased, adaptive implementation process.

The ecological component of the feasibility study could also be enhanced by presenting proposed ecosystem improvements within a more systematic framework. Ecosystem restoration projects are presented in the feasibility study as a large menu of possible selections, but without clear, science-based and system-wide themes to help prioritize possible projects. Although all of the projects could conceivably have merit and contribute to restoration goals, the prioritization, constraints, and prospects for success of these individual projects could be better explained because there is no clear sense of which projects would be the most useful and in what sequence they might be implemented (given the large number and variety of proposed measures, along with limited resources for their implementation, some type of sequencing is inevitable). The ecological portion of the study is thus framed primarily in terms of individual, site-specific projects, where the degree of restoration depends on the size and number of projects and overall dollar expenditures. The first- and second-tier goals require clarification, further explanation, and tighter linkages with the details of project alternatives if they are to serve as useful guiding themes.

The ecosystem component of the study is of mixed value because, even though it contains a large number of possible restoration measures and a great deal of information, it lacks clear explanations of the relative importance and priorities of these measures and their relationships. The limited degree of coherence within the ecosystem portion of the study renders communication and evaluation of the study's details very difficult, and individuals unfamiliar with the study are challenged to clearly understand its structure, key assumptions, methods, metrics, and conclusions. The ecosystem component of the study also discusses critical historic properties along the river, as well as recreational boating, hunting, and social and economic issues. These factors are relevant to river ecology, and the effort to consider such variables in an attempt to increase the study's multidisciplinary character is commendable. It is not clear, however, how these considerations enter into decisions related to ecosystem improvements within the feasibility study.

Integration and Trade-Offs

As explained earlier in Chapter 2, there are several prominent impacts and trade-offs between commercial navigation and river ecology within the

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UMR-IWW system. Many of these impacts on river ecology stem from the construction and subsequent operations of the navigation project, such as the ecological effects of the navigation pools and the direct impacts of barge traffic on fish mortality rates. Some impacts, however, occur in the other direction, such as when low or high water levels affect shipping (e.g., low flows in the summer of 1988, Mississippi-Missouri River floods of 1993). There are many other users of the system and they affect each other in a mixture of complementary and conflicting ways. As explained in the report from the Phase I committee, not all of these uses are fully compatible and not all users may be able to always fully enjoy the system's benefits as they wish: "Striking the proper balance between the multiple uses and users and thereby protecting the public interest requires denying some potential users access when they want it" (NRC, 2001). Given the prominence and importance of the interconnections and trade-offs between the 9-foot channel project and river ecology, these linkages should be clearly defined and presented within the feasibility study.

Biologists have documented trends indicating there is little uncertainty regarding a long-term decline of fish and wildlife resources in the UMR-IWW (USGS, 1999; Wiener et al., 1998). There have been many ecological changes across the UMR-IWW region during the past several decades that have affected river ecology in numerous and only partly understood ways. Construction of the dam and navigation pool system in the 1930s and its subsequent operations have clearly played a large role in the river system's declining ecological trends. Accordingly, declining trends may continue as long as ecosystem restoration actions are constrained by the operations of the 9-foot channel project. It is reasonable to assume that the 9-foot channel project will continue to be operated and maintained, but it is also reasonable to assume that changes in the configuration and operations of the commercial navigation channel may be necessary to achieve different levels of ecosystem recovery. Trade-offs such as these will be integral to major UMR-IWW decisions in the future. Such trade-offs will be controversial, and decision makers should be provided good economic and environmental information in order to anticipate such trade-offs and forge polices that reflect society's best interest.

The ecosystem restoration plans presented in the feasibility study, however, pay scant attention to how restoration measures might affect other users of the system, such as commercial navigation. Although the study identifies and explains some of the impacts of the navigation pool system on river ecology, the possible effects of prospective restoration measures on commercial navigation are not broadly considered. Within the study it is stated, for example, that "pool-scale drawdowns can be accomplished while maintaining navigation" (USACE, 2004, p. 167). This is certainly a true

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statement as it applies to this specific issue. But in a broader sense it illustrates the study's general assumption that meaningful restoration can be accomplished without disturbing commercial navigation and that linkages and trade-offs between these two sectors thus need not be carefully evaluated. Small drawdowns that do not affect navigation are likely to yield small degrees of river ecosystem recovery. More challenging situations will arise if greater degrees of ecological restoration are desired in the future, and if proposed restoration actions, such as pool-scale drawdowns, would affect navigation. These types of trade off decisions pose the greatest challenges to decision makers and stakeholders. The feasibility study will be strengthened by identifying these types of prospective trade-offs and explaining the economic and environmental implications they may entail.

Implementation

Implementation of the ecosystem component is discussed near the end of the feasibility study. Several "adaptive implementation" options are described, with variations in initial years authorized and oversight and approvals requested. The study proposes a 15-year implementation plan, listing three criteria that will be considered in the adaptive framework: (1) best return on investment, (2) best gains in diversity, and (3) additional knowledge required to guide future investments.

Although references to adaptive management concepts within the study are encouraging, these discussions suffer from lack of clarity, detail, and consistency. For example, it is not clear in what units "best return on investment" will be measured, how it is to be measured, and who will do the measuring. The same concerns hold for the "best gains in diversity" criteria. Furthermore, it is not clear how these criteria relate to the many other criteria being used in the study (e.g., first- and second-tier goals). There is also inconsistency in the presentation and use of key terms and concepts. For example, p. 516 describes adaptive management as "a process that seeks to aggressively use management intervention as a tool to strategically probe the functioning of the ecosystem. . . . It uses management actions as tools to not only change the system, but as tools to learn about the system." This may be a reasonable definition, but the ecological section of the feasibility study does not explain how adaptive management concepts, such as ecosystem monitoring, policy adjustments, and stakeholder collaboration, are to be used during implementation of various ecosystem improvement measures. Such examples of inconsistency and lack of clarity make it difficult to understand how ecosystem improvements are to be implemented (time scale, resources, priorities), how their results are to be monitored, which

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group(s) will be responsible for monitoring responsibilities, and how monitoring results might be applied to changes in project selection or operations policies.

Finally, there is only limited discussion regarding the possibilities of integrating feasibility study implementation with the scientific initiatives and studies of the Environmental Management Program. The Corps has provided resources to and actively participated in the EMP since its inception in the mid-1980s. During that time the EMP has sponsored a broad array of ecological investigations and research on the Upper Mississippi River. The EMP produced one of the more comprehensive reports on Upper Mississippi River ecology and changes over the past century (USGS, 1999), and the program is considered by many as one of the nation's premier river ecosystem programs. The EMP is mentioned numerous times throughout the feasibility study, but there is little explanation of how the alternative selected in the feasibility study was to be informed by the scientific studies and findings generated by the EMP.

Commentary and Recommendations

The effort of "restoring" ecological structure, functions, and habitat in an ecosystem as large as the UMR-IWW is essentially unprecedented, and there is no blueprint that can be used to guide restoration efforts there. The Corps and collaborating federal and state agencies should thus aim to make progress toward restoration in a process of learning in which both successes and failures are to be expected. The Corps should also seek to draw on lessons and experiences in other large river systems. There are, for example, ongoing restoration efforts in the Danube and Rhine rivers in Europe. Experiences in other large rivers around the world may also be useful in learning how other nations have addressed management challenges similar to those in the UMR-IWW.

Ecological restoration on the scale of the UMR-IWW does not represent a traditional civil engineering project; managing the diverse resources across the UMR-IWW is a process in which the Corps is likely to be involved for at least the next several decades. Engineering concepts and expertise are often important components of ecosystem restoration, but the UMR-IWW is not a "project" that will be designed, constructed, and turned over to a local sponsor. Sound, integrated management of the UMR-IWW and its related resources may thus require a broadening of traditional Corps of Engineers management paradigms. The scope and novelty of system-wide ecosystem restoration on the UMR-IWW and the dynamics of the system point to the importance and value of an adaptive management ap-

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proach. An adaptive approach would encourage actions that are reversible and that hold promise for both improving ecology and improving understanding and knowledge. An adaptive approach would also promote management actions based on scientific knowledge and theories, gained in monitoring the UMR-IWW (recommendations from a 2004 National Research Council report [NRC, 2004d] on the Corps of Engineers and adaptive management may provide useful advice in this area).

The relations between commercial navigation and river ecology lead to another point that should be considered in UMR-IWW restoration: compromises between users will be necessary if the system will continue to be operated to support both commercial navigation and an ecosystem restoration program. A balanced UMR-IWW navigation and ecology (and other sectors) program would identify ways in which these sectors affect one another and consider how modifications in one sector could benefit other sectors. Possible trade-offs include changes in the length of the navigation season to allow for periodic pool drawdowns and temporary changes in channel depth for drawdown purposes. Such trade-offs nearly always entail increased benefits for some sectors and reduced benefits for other sectors, and are conducted in principle to realize a net increase in social benefits. Such trade-offs are naturally resisted by groups that stand to have their benefits reduced. The Corps and other federal and state agencies will be challenged in identifying and implementing promising trade-off-type policies, but they should continue to build upon a good record of interagency cooperation and past experiences, such as an experimental drawdown conducted at Pool 8 in 2000.

Finally, restoration efforts on the UMR-IWW should continue to look for scientific guidance to the evolving literature on large river floodplain science and restoration, and to findings from the Environmental Management Program, one of the nation's best examples of a large river ecosystem monitoring and science program. Linking proposed restoration actions to larger, science-based theories would lend structure to overall restoration efforts and help prioritize restoration measures. Focusing on measures that reconnect river and floodplain and restore some pre-settlement hydrologic processes would also provide quantifiable and scientifically credible metrics for assessing the progress of restoration measures.

The ecological dimensions of the study could be strengthened by focusing efforts on restoring system-level hydrology and by broadening efforts to reestablish connectivity between the floodplain and river channel (or increasing the number of acres that can receive floodwaters during high flows) in areas where these connections have been disrupted by flood management projects and where there is support for alternative approaches (including willing sellers of leveed

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lands). The feasibility study should also more explicitly acknowledge and explain the interconnections between different users within the UMR-IWW and explore some of the key trade-offs that are likely to be part of future UMR-IWW management decisions. The feasibility study should be based clearly and explicitly on adaptive management principles, which rest upon both strong stakeholder collaboration and adequately funded, sustained monitoring programs. Management actions and policies regarding UMR-IWW resources should clearly incorporate and build upon past and ongoing monitoring and science programs of the federal-state interagency Environmental Management Program.

PROPOSED NAVIGATION IMPROVEMENTS

Background

In stating that a need for action exists, the Corps feasibility report notes that "Waterborne commerce has more than tripled over the past 35 years—growing from about 27 million tons in 1960 to 84 million tons in 1995" (USACE, 2004, p. 13). The feasibility study also describes congestion at selected locks in the Upper Mississippi River and Illinois Waterway systems, noting that 11 locks (8 on the UMR and 3 on the IWW) have been listed among the "top 20 locks in the country with the highest average delays" (USACE, 2004, p. 13).

The UMR-IWW navigation systems are described as "essential to the economies of the counties and States that they border" (USACE, 2004, p. 16). The feasibility study also states that within the study area, "21,891 man-years of employment are generated by water-based industries" and that "over $509 million" in income is generated by associated businesses (USACE, 2004, p. 16). It further argues that maintaining an efficient inland navigation system is critical to national defense (USACE, 2004, pp. 14-15). The primary justification for navigation improvements, however, rests on the possibility of increased commercial navigation in the future. The Corps feasibility report presents five alternative scenarios of unconstrained river traffic, in which postulated year 2050 movements on the UMR-IWW system range from 78.8 million to 138.0 million metric tons, compared to year 2000 levels of 81.8 million metric tons. Four of the five scenarios assume significant positive growth rates in total commodity movements (USACE, 2004, pp. 73-78).

The argument for action based on existing conditions generally rests on two claims: (1) there has been steep growth in commodity movements over

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the past 35 years, and (2) the system of locks and dams is old and deteriorating. With respect to the first claim, it is true that total annual commodity movements on the Upper Mississippi River system (including IWW) increased from 34.4 million metric tons in 1965 to 76.5 million metric tons in 2002 (2003 figures are not yet published).[2] This corresponds to an average annual increase of 2.18 percent. These statistics, although accurate, present only a partial picture of past export trends. There was, indeed, growth in shipments in the 1960s and 1970s. However, as noted in this committee's first report, there has been virtually no change in total Upper Mississippi River commodity shipments since at least 1984 (NRC, 2004a; see also Figure 3-1). According to Figure 3-1, annual commodity movements on the Upper Mississippi River in 2002 were approximately 83 million metric tons; the corresponding figure for 1984 was roughly 81 million metric tons. Close examination of available data yields no convincing evidence of a positive growth trend in river traffic, either now or at any time since the early 1980s.

With respect to the second claim, there is no doubt that the system of locks and dams is relatively old: 32 of the 37 main chamber locks were constructed before 1954 (i.e., they are more than 50 years old). However, with the exception of the Mel Price lock (constructed in 1990), nearly all main chamber locks have received some form of major maintenance or major rehabilitation at some point in their life. Major maintenance or rehabilitation projects have been completed on 21 locks during the past ten years (1994-2003) alone. These projects are described as:

> projects to repair/replace degraded electrical systems, unreliable machinery, deteriorated lockwalls, lock gates, etc. The purpose of the rehabilitation projects was to restore performance or to ensure reliable performance and avoid the consequences of lengthy closures or slowed lock performance. (USACE, 2004, p. 46)

Although lock malfunctions occur, and delays are common in certain parts of the system, there is no clear evidence that the navigation system as a whole is deteriorating or that its capacity is declining over time. In fact, the feasibility study concludes that "the life of existing locks and dams can be extended for another 50 years with normal periodic rehabilitation and match the design life of any new construction" (USACE, 2004, p. 78). The projection of the "without-project" condition assumes that such rehabilitation programs would take place. Accordingly, even if deterioration of the infrastruc

[2]Data from Table 4-1, p. 39, USACE (2004) converted to metric tons. The source of these data, the Waterborne Commerce Statistics Center, presents all data in short tons (2,000 pounds).

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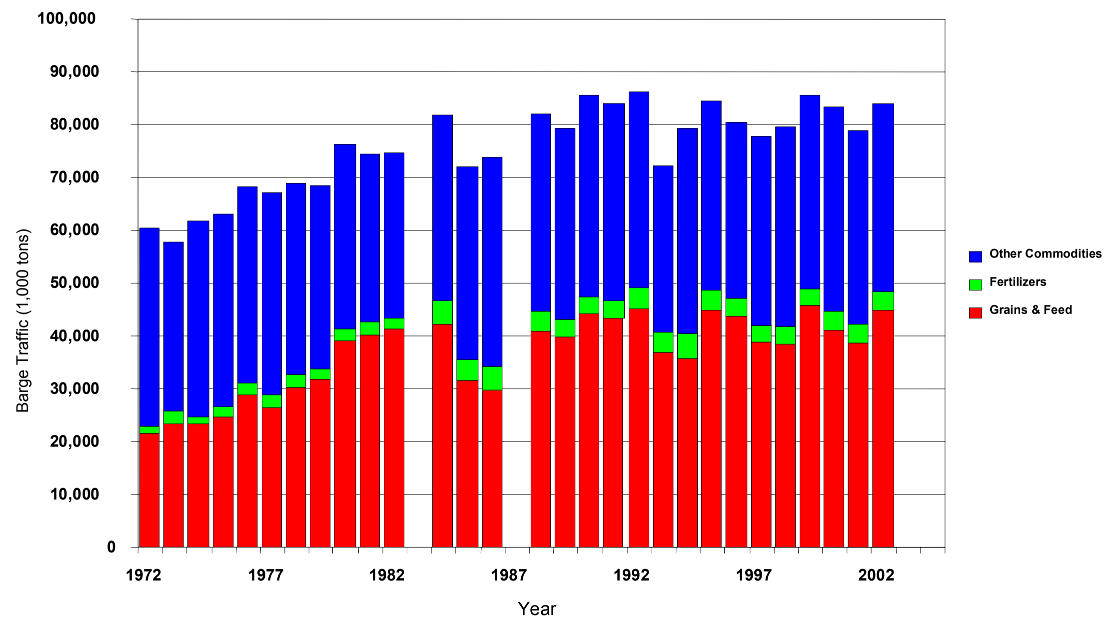

FIGURE 3-1 Commodity movements on the Upper Mississippi River. SOURCE: U.S. Army Corps of Engineers, 2004.

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ture is an issue, it will be corrected in approximately the same time frame regardless of whether the proposed navigation improvements are constructed.

Available information for the study area indicates that both the demand for and the supply of waterway transportation capacity are static in the recent past and at the present time. There is no observed growth in traffic, and there is no indication of a decline in capacity now or in the medium-term future, given the Corps' major maintenance-rehabilitation program. This committee is not aware of any studies demonstrating that these congestion levels are significantly constraining current shipments of grain or other commodities. The finding under Scenario 1 in the Corps feasibility study, in which traffic would remain approximately at 2002 levels throughout the study period, is that structural measures are not cost justified.

Forecasting Waterway Shipping Levels

If existing conditions do not justify major structural improvements to the navigation system, the argument must rest on an assumption of increased levels of future waterway traffic. In the absence of improvements or other actions to reduce congestion, increased traffic would lead to increased congestion, increased shipping cost, shifts of commodity movements to other forms of transport, and potentially (in extreme cases) reduced grain exports. Examination of this possibility begins with consideration of future demands for water transportation in the UMR-IWW system.

Commercial river traffic includes two major categories of cargo: grain and other commodities. Grain shipments include corn, soybeans, wheat, meal, and other farm products. Of these products, corn has accounted for the largest share. Other (non-grain) commodities include coal, coke, petroleum products, fertilizers, iron and steel, industrial materials, and construction materials. In recent years, non-grain commodities have comprised approximately 48 percent of total barge movements (Sparks Companies, 2002, p. 7). Forecasting future commodity movements is complicated by uncertainties regarding demand and supply functions for the subject commodity, both in aggregate and by region; costs, capacities, and regional accessibility of alternative transportation modes; and other factors pertaining to the navigation system itself. This process is particularly difficult for grains bound for export, where world market conditions (demands, supplies, prices, transportation costs) also impact commodity movements. It is exceptionally difficult to develop credible grain export forecasts that extend beyond five to ten years into the future (John C. Beghin, Iowa State University, personal communication, 2004). The Phase I NRC committee that reviewed the feasibility study urged the Corps to use a scenario approach to traffic forecasting so as to reflect the considerable uncertainty attached to

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any particular number (NRC, 2001). The Corps deserves credit for adopting this suggestion; however, the way in which it was implemented requires some comment.

The Corps engaged the services of Sparks Companies, Inc., of Memphis, Tennessee to prepare the initial U.S. grain export scenarios. Sparks developed five scenarios for grain movements. Each scenario reflects a set of assumptions regarding world grain markets and domestic supply conditions. The assumed relationships are noneconomic: in the case of the Central Scenario, international trade is created by predicted country and regional imbalances in production and consumption, U.S. exports are the residual of international trade after subtracting assumed shipments by other surplus producers, and Mississippi River exports are a fixed fraction of U.S. exports. Mississippi River exports are then restated as barge movements on the Upper Mississippi River system. The other four grain export scenarios are generated by specifying deviations from the Central Scenario (there is no rebalancing of production and consumption).

As in the report from Sparks Companies, Inc., the feasibility study reflects five scenarios for grain movements (Figure 3-2; USACE, 2004, p. 75). The Hypoxia Scenario from the main body of the 2002 Sparks report was replaced by a Less Favorable Trade Scenario in the Corps report. Otherwise, the Corps report closely follows the Sparks report. Four of the five scenarios show steadily increasing grain shipments; only one (Least Favorable Scenario) assumes falling shipments. Multiple scenarios were not employed for other (non-grain) commodities, despite the fact that they account for nearly 50 percent of river traffic at Lock and Dam 27. Instead, single-point forecasts were used for the full 50-year planning period, despite very large uncertainties. In the Sparks Companies, Inc. report, forecasting models developed in the mid-1990s by Jack Faucett and Associates were adopted, results for a different base year were adjusted, and assumptions were modified where necessary. The result was a single forecast for each commodity group. Taken together, other (non-grain) commodities are predicted to grow at an average rate of 0.8 percent per year. When the forecasts of other commodities are combined with the grain shipment scenarios, the result is five combined scenarios of unconstrained river traffic. The 50-year average annual growth rates for these scenarios are shown as Table 3-1.

The specification of scenarios is one of several ways to deal with high levels of uncertainty concerning future events. Each scenario is, in effect, a "story" that presents an integrated set of postulated future events or conditions (Ascher, 1978). Ideally, elements of each scenario are nested, so variables that depend on other variables or conditions are clearly identified. In this respect, the grain export scenarios are well designed, proceeding from a

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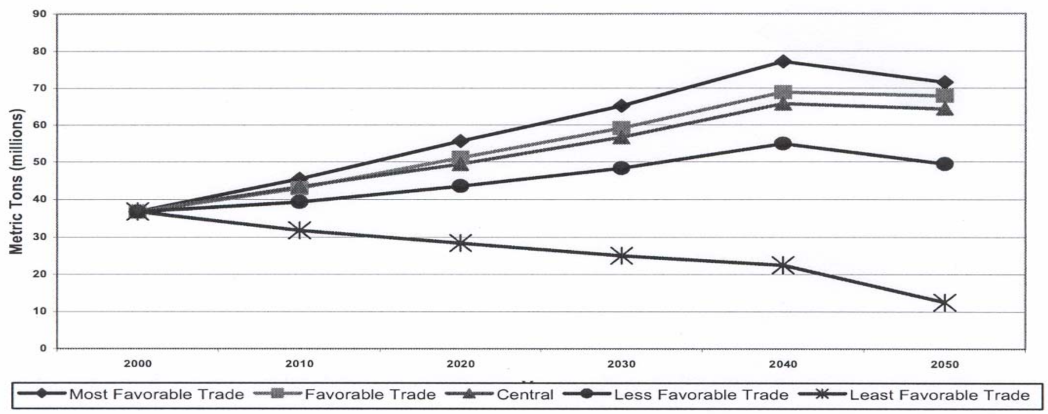

FIGURE 3-2 Upper Mississippi River System forecasts of total farm product movements by scenario.
SOURCE: USACE, 2004, p. 75.

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TABLE 3-1 Average Annual Growth Rates Implied by Barge Traffic Scenarios

Scenario	Average Annual Growth Rate (%)
1	- 0.07
2	0.70
3	0.94
4	1.00
5	1.05

SOURCE: USACE, 2004.

few top-level, key "drivers," through a hierarchy of successively more detailed variables. However, the barge traffic scenarios summarized above are flawed, since they each incorporate the same "story" for movements of non-grain commodities. The practice of merging scenarios with single-point forecasts might be acceptable if non-grain movements were relatively small or if forecasts of non-grain movements were relatively certain. Neither condition is true. Non-grain movements constitute nearly 50 percent of the total, and the 50-year forecasts employed for these commodities, based on decade-old data, can be described only as speculative.

Another criterion for effective scenario design is that the scenarios should represent a wide and balanced range of possible outcomes. Generally, scenarios are included for extreme events at both ends of the span of possibilities. Although it is not possible to state objective probabilities for individual scenarios, the most extremely optimistic scenario and the most extremely pessimistic scenario should have similar subjective probabilities. In most cases, the median scenario captures those conditions and outcomes that are believed to be most probable.

The first report from this committee expressed skepticism as to whether the Sparks grain export scenarios actually represent a wide and balanced range of possible outcomes (NRC, 2004a). Since publication of that report, the committee reviewed the documentation in more detail and met with representatives of Sparks Companies, Inc. in December 2003 at a meeting convened in St. Louis. Key concerns related to the analysis in the 2002 Sparks Companies, Inc. report focus on two questions: (1) Can Scenarios 1 and 5 be described as having similar subjective probabilities? (2) Can the median scenario be fairly described as the most likely future? The answer to both questions appears to be no.

Barge traffic Scenario 5 may well represent an extremely optimistic future of U.S. grain exports, but it is hard to believe that Scenario 1 reflects a similar, extremely pessimistic future. Since neither scenario reflects uncertainty in the prediction of non-grain shipments, the range of possible future conditions is

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surely skewed and substantially understated. In fact, of all the scenarios, Scenario 1 most closely replicates the conditions of the past two decades. More pessimistic outcomes (i.e., steeper declines in grain exports and/or declines in shipments of other commodities) are certainly plausible and could be affected by factors such as U.S. farm policy, increasing domestic demand for corn (e.g., for ethanol production or for finishing livestock for export), changes in international terms of trade, rising grain production in other countries, or rail competition for movement of non-grain commodities.

In discussions with Sparks Companies officials, as well as other experts, the committee attempted to determine the reason for believing that the grain export trends implied by Scenario 3 should be considered the "most likely" as compared to, say, a continuation of more than 20 years of a flat or declining export trend. At a minimum, the same logical structure used to predict rising exports in the future should be capable of explaining the flat exports trend of the past two decades. Sparks Companies officials disagreed with this view. The committee, however, remains skeptical of the implication that the Scenario 3 grain export forecasts are the most likely future outcome.

The barge movement scenarios used by the Corps are flawed by the incorporation of highly uncertain point forecasts for non-grain movements. Further, the grain shipment scenarios, although individually well designed, are collectively too narrow and skewed. Scenario 3 cannot be treated as a most likely outcome, and Scenario 1 does not represent the most pessimistic plausible outcome. As it continues its analysis, the Corps should take advantage of the many available forecasting methods for developing scenarios rather than relying on those provided by only one contractor. The use of methods and approaches that employ more sophisticated methods, including consideration of macro-drivers and analysis of potential system shocks, would considerably strengthen the forecasts. Furthermore, the Corps should seek independent expertise to aid in the development of credible forecasts to be used in conjunction with scenarios.

Non-grain shipments on the UMR-IWW are roughly half of total commodity shipments. A more complete set of scenarios of UMR-IWW waterway traffic would thus, in addition to considering the possibility of both increases and decreases in grain commodity shipments, consider possible increases and decreases in non-grain commodity shipments.

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Reducing Waterway Congestion

The purpose of proposed navigation improvements on the UMR-IWW is to reduce congestion at the locks so as to reduce the cost of commodity shipments. The degree of expected congestion at any given lock varies widely throughout the system, generally increasing as one moves down river. Various metrics are used to describe congestion, including average waiting time per tow, percentage of tows delayed, and ton-hours of delay. Using 1993-2001 data, the Corps identified the most congested locks as UMR locks 20-25 and IWW LaGrange and Peoria locks (USACE, 2004; see Appendix A in this report). Significantly, all of these locks have 600-foot main chambers.[3] Based on 1990 data, only 13.1 percent of tows using UMR lock 25 were able to lock through without reconfiguring at the lock. Another 8.6 percent (knockout singles and setover singles) could be reconfigured in the lock chamber and processed as a single lockage. However, the majority of tows must be split into two parts and locked through in two operations (or "double-cut lockages"). The most common double-cut configurations are those of 15-barge tows, which are approximately 1100 feet long.

Based on this characterization of the problem, there are two possible approaches to reducing congestion: (1) structural changes that replace certain 600-foot locks with 1200-foot locks and (2) other measures that reduce average processing time at existing locks such as operational changes and small-scale structural alterations. The actions included in the second category are described here as nonstructural measures. Some nonstructural measures are already in use and/or planned for the future and include the following (USACE, 2004, pp. 79-81, 156):

- *Helper boats*. Auxiliary towboats are stationed at certain locks to assist tows in making approaches to locks under adverse current conditions (outdrafts). This measure is already in use, as needed, at UMR locks 20-25.
- *Industry self-help*. A towboat waiting in the queue disengages from its own barges and assists the tow being processed. This measure is in limited use, affecting only about 1 percent of all lockages.
- *N-up/N-down servicing*. When both upriver and downriver queues exist, a lockmaster can reduce overall service time by processing several consecutive tows from each queue in turn (e.g., 3 up, then 3 down). This measure reduces total approach time at the expense of increased time for

[3] Three UMR locks (19, Mel Price, and 27) have 1200-foot main chambers. The IWW T.J. O'Brien Lock has a 1000-foot chamber.

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turning back the lock chamber. The average net savings is stated as 6 minutes per double-cut lockage.

- *Deck winches*. Permanent deck winches on barges reduce the time required to reassemble the tow after a double-cut lockage. At present, one company has equipped all of its barges with deck winches, but the Corps does not foresee any further adoption of this measure (Dyer et al., 2003, pp. 13-14).
- *Switchboats*. Under this proposal, switchboats would be permanently stationed at congested locks to assist with double-cut lockages by extracting unpowered cuts and moving them clear of the lock for reassembly (essentially an expansion of the industry self-help measure). The Corps determined that implementation of this measure would require new authorization and appropriation.
- *Mooring facilities*. For some locks, the provision of tie-off facilities closer to the lock chamber has the potential to reduce approach times and therefore to reduce overall servicing time. The Corps determined that implementation of this measure would require new authorization and appropriation.

Recreational vessel lockages are not considered a significant contributor to UMR-IWW congestion, even at anticipated future waterway traffic levels. Accordingly, no measures for increasing the efficiency of recreational vessel lockages are considered.

The 2001 report from the Phase I NRC committee recommended that all feasible and beneficial nonstructural measures should be implemented prior to any determination of the merit of structural improvements (NRC, 2001). This committee's first report reiterated this principle (NRC, 2004a). To restate this point, a benefit-cost analysis of structural measures is based on a without-project condition—a projection of what the future would be if specific structural improvements are not built. This projection would logically include all available measures that are capable of reducing congestion cost-effectively, whether or not these measures require congressional authorization and appropriation. The only condition is that their implementation, under without-project conditions, is reasonably likely. The without-project condition defined in the feasibility study does not follow the practice described above. As discussed below, no satisfactory attempt has been made to include all feasible, beneficial, nonstructural measures. Also, some measures (mooring facilities and switchboats, which require new budget appropriations) have been made a part of the with-project condition.

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Nonstructural Measures

Consideration of nonstructural measures began early in the feasibility study, with identification and preliminary screening of 92 possible measures (USACE, 1995). A subsequent Corps study completed the screening process for these measures (USACE, 1999). This resulted in a list of 12 "small-scale measures" that were subjected to further evaluation (USACE, 2004, p. 142). Final results are summarized as follows:

1. Measures included in the without-project condition:

- Helper boats at present levels of usage
- Industry self-help at present levels of usage
- Permanent deck winches at present level of adoption
- Powered ratchets, assuming low level of future adoption by industry
- N-up/N-down lock operations

2. Measures retained for evaluation and possible inclusion in the with-project condition:

- *Switchboats*. These were found to be feasible and beneficial when applied to UMR locks 11-13 and 20-25; included in the Corps' Preferred Plan.
- *Mooring facilities*. These were found to be feasible and beneficial when applied to UMR locks 12, 14, 18, 20, 22, 24 and the IWW LaGrange lock; included in the Preferred Plan.
- *Deck winches combined with an excess lockage time charge*. The Corps contracted with the Volpe Transportation Systems Center to evaluate this alternative. The report from the Volpe group concluded that it is not likely to be beneficial (see discussion in next section; Dyer et al., 2003).
- *Traffic management*. The Corps considered congestion fees, tradable permits, and other forms of scheduling. The tradable permit alternative was reviewed by the Volpe Center (see discussion in next section; Dyer et al., 2003). It was concluded that these measures are either not feasible, not beneficial, or both.
- *Appointment system*. This measure would utilize the existing Operation and Maintenance of Navigation Installations (OMNI) data recording system to allow operators to call ahead one or more locks for lockage appointments. Limited evaluation of this measure was performed, with a conclusion that it could reduce fuel and other operating costs, but would

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not necessarily relieve congestion. It was not included in the Preferred Plan.

- *Other scheduling systems*. Various suggestions for master scheduling systems have been received by the Corps, including one from the University of Missouri (Ronen and Nauss, 2003). In the feasibility study, however, it was concluded that these proposals are infeasible. No form of any scheduling system is included in the Preferred Plan.

Evaluation of Nonstructural Measures: The Volpe Center Report

The U.S. Department of Transportation's Volpe Center was retained by the Corps to identify a limited number of nonstructural measures for reducing congestion and to conduct an economic evaluation of those that were found potentially feasible and beneficial (Dyer et al., 2003). After data collection, meetings with experts and users, and preliminary screening, two measures were identified in the Volpe report for further analysis:

1. *Excess lockage time fees*. It was postulated that a fee for some measure of excess lockage time would provide an incentive for industry to adopt permanent deck winches, thus reducing service times for double-cut locks. This is the same measure described in the Corps feasibility study as "deck winches and excess lockage time charges."
2. *Tradable permits*. Three variants to this approach were considered in the Volpe report: (1) pre-issued tradable permits for specific times, (2) pre-issued tradable permits for place in queue, and (3) tradable place-in-queue permits issued at the lock.

Excess Lockage Time Fees. The excess lockage time charge proposal was defined in the Volpe report as a fee high enough to cause all operators to install permanent deck winches on all barges. The actual fee was never specified in the analysis. Instead, the benefits of universal deck winches were contrasted with the costs. Benefits are calculated as the savings in vessel operating costs (including vessels in queues) while costs are based on the installation, maintenance, and replacement of the winches. Based on this approach, benefit-cost ratios were calculated in the range of 0.49 to 0.53 in the Volpe report, indicating an infeasible measure. There are, however, flaws in this analysis.

One flaw is that establishing an excess lockage time fee (however determined) so high as to cause all operators to install deck winches would likely be economically harmful and thus unacceptable. A more realistic proposal would be to set a fee corresponding roughly to the social oppor-

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tunity cost[4] of the "excess" time. This process should consider, at a minimum, the costs borne by the tow being locked, other tows in the queue, and the Corps. An estimate could then be made of the number of barges that would be fitted with winches in response to that fee (based on a study of barge operator characteristics and economics, certainly something less than 100 percent). This estimate would lead to a calculation of reduced maneuver time at locks, which would lead to an estimate of reduced delay times and then to a partial measure of benefits (there may be other components). In this formulation, costs are similar to those defined in the Volpe report, except that fewer winches would be installed.

A crucial part of the analysis is the assumed time savings associated with processing a winch-equipped, double-cut tow. The report from the Volpe group examined the experience of the single company that has equipped all of its barges with deck winches. Examination of the probability distributions of that company, compared to other operators, revealed that the company with the deck winches had many fewer lockages in the fourth quartile of maneuver time[5]. The time savings for each lock were then calculated by assuming that all fourth-quartile lockages would be processed at third-quartile maneuver times. This approach is clearly arbitrary and represents another flaw in this analysis. There is no reason to believe that fourth-quartile lockage times will be reduced to third-quartile levels (the reduction may be more or less). Similarly, there is no reason to believe that third-, second-, and first-quartile lockage times will not be reduced at all.[6]

Much of the data on the effectiveness of this measure used in the Volpe study was available because one large towing company had previously installed deck winches on its barges. This action was said to have been justified by the incidence of injuries to deck hands resulting from the former line-handling procedures. If true, this implies that companies can expect substantial benefits in the form of reduced insurance costs, lost time, and so on. These benefits were not included in the analysis. They are described as "not part of the scope," but in a voluntary program they would be very much part of the considerations of a company contemplating implementation (Dyer et al., 2003, p. 48).

The benefit measures employed in the Volpe report are not well documented, but they appear to be confined to avoided short-run costs (payroll,

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[4] In this instance, "social opportunity cost" is the additional cost borne by society as a consequence of excess lockage time. It includes costs borne by the Corps, tow operators, shippers, and commodity producers. Costs are generated by a tow that is being locked, as well as by tows that must thereby wait longer in a queue.

[5] The "fourth quartile" refers to the set of lockages that constitute the slowest 25 percent of all lockages.

[6] The latter point is acknowledged in the report from the Volpe group (Dyer et al., 2003, p. 48).

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fuel, etc.). One issue not investigated in the Volpe report, or elsewhere, is the long-run cost of delay. If a towing company experiences chronic delay, that effectively reduces its capacity to move commodities with its existing fleet. If the company is able to increase its tariff sufficiently to compensate for this loss (as well as any increased short-run costs), it may be indifferent to the delays, but the cost will have been passed on to shippers and, further, to their clients. If competitive conditions preclude a fully compensatory increase in the tariff, then the towing company has two choices: (1) purchase and operate additional barges and towboats to regain lost capacity, and (2) incur the costs associated with lost business. In any of these cases, it appears that avoided short-run costs may underestimate the true benefits of congestion reduction.

It should be noted that it was suggested in the Volpe study that partial implementation of deck winches would lead to an even lower benefit-cost ratio (Dyer et al., 2003, p. 48). The opposite, however, is the case. Given that implementation on the part of operators is voluntary, only those who foresee private benefits exceeding the costs will take this step. If the excess lockage fee is at least equal to the social opportunity cost of the time saved and if any operator voluntarily installs winches as a result of this fee, a benefit-cost ratio in excess of 1.0 is guaranteed. This does not imply any particular degree of implementation or congestion reduction (that must be estimated through analysis), but it promises that whatever happens will be beneficial.

Tradable Permits. The analysis of tradable permits within the Volpe report addresses three configurations, all of which are judged infeasible and not subjected to any quantitative evaluation. Two of the three options involve a fixed, long-term scheduling system (permits issued at the beginning of the navigation year on the basis of an assumed schedule), which is argued to be impractical for U.S. inland waterway navigation. With respect to the assumed schedule, the argument is persuasive. Whether that admittedly impractical schedule could serve as an acceptable basis for the initial distribution of tradable permits is another question that is not fully explored in the report. The third option allows tows to trade places in a queue, based on trading of place-in-queue permits issued on arrival. No quantitative analysis of this option was conducted, however, so there is no information regarding the efficiency of any of these trading options. Since towing companies base decisions on their private costs, they would be expected to trade queue positions whenever the differential in private costs between the trading tows justifies such a move. This kind of transaction is inherently

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efficient, provided it leaves other tows unaffected.[7] However, no analysis is offered.

The Corps also reported an investigation of a "congestion fee." This measure was evaluated separately as "alternative 2." As described, however, it does not correspond to the technical definition of a congestion fee. The proposal is for a fixed fee levied on all commercial users of the locks, whether congestion is present or not. As such, it is better described as a "lockage fee." Based on the Corps' estimates of the price elasticity of water transportation, this measure appears to produce significant benefits at very modest cost. In fact, based on analysis conducted within the feasibility study, it was found that the lockage fee resulted in the largest net benefits of any alternative considered for 14 of the 15 combinations of traffic-benefit assumptions (USACE, 2004, p. 201). Nevertheless, the lockage fee was rejected as a possible strategy because (1) implementation would require a change in federal law that bans user fees, (2) no such fee has been attempted on any other U.S. waterway, and (3) the fee had questionable policy implications. The third point refers to the origin of the benefits: the fee would drive marginal users off the waterway, possibly transferring shipments to less environmentally- or socially-desirable modes of transport (this latter concern does not appear to have been investigated).

Measures Not Considered: Nonstructural Waterway Traffic Management

Despite a decade of review of "small-scale" measures, the consideration of nonstructural approaches to congestion management within the feasibility study is substantially incomplete. One major omission has been the failure to seriously consider a real-time traffic management system. Such a system could be designed as an expansion of the existing OMNI data collection system or as a variant of the Vessel Traffic Services (VTS) system operated by the U.S. Coast Guard in major ports. The basic requirements are that the system operator be continuously aware of the location, direction, speed, and short-term intentions of all commercial traffic on the river. Towboats could then be advised of their position in a queue before arriving at a lock and, if desirable, tows could be re-sequenced en route. One benefit of such a system is that it expands on the information available to towboat captains from the existing OMNI system, improving their ability to conserve fuel and to schedule maintenance and servicing. Although this result contributes to lower water transportation costs (the

[7] In practice, tows may have to be reordered prior to joining the queue so that tows changing places do not increase approach times and thus delay other tows. The solution to this problem lies in a real-time scheduling system, as discussed below.

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study's ultimate objective), it does not directly reduce congestion. The major benefit of a real-time traffic management system is the platform that it provides for various strategies to improve the efficiency of lock operations.

For example, the third trading alternative considered, but not evaluated in the Volpe report, involves the trading of place-in-queue permits in which permits are issued as tows join the queue. To be fully effective, this alternative requires that approach times not be compromised in the course of re-sequencing queues. A real-time traffic management system would allow the place-in-queue permits to be assigned as tows depart the previous lock, providing time for operators to negotiate trades while under way, and further allow for re-sequencing to occur before tows reach the queue.

A potentially more effective strategy may lie in a large body of Corps-funded research performed on the Ohio and Upper Mississippi Rivers over the past decade that has explored a range of decision rules for lock operations and for minimizing transport costs (see, for example, Kim and Schonfeld, 1995; Ting and Schonfeld, 1996, 1998a, 1998b, 1999, 2001a, 2001b; Wei et al., 1992; Zhu et al., 1999). These papers describe various ways of scheduling and sequencing tows to minimize overall delay time and/or transportation cost. The findings are too extensive and detailed to summarize here, but one example may suffice, taken from Ting and Schonfeld (2001b). The authors simulated operations at Ohio River lock 22 and UMR lock 25, using data from the Corps 1987 Lock Performance Monitoring System to generate service time regressions. They considered, among other things, a lockage priority rule that places tows with minimum expected service time per barge first in the queue (the "shortest processing time" (SPF) rule). This measure alone substantially reduced simulated congestion at the Ohio River lock. When compared to the existing first-come-first-served rule, the SPF rule reduced per-barge delay by 8.5 percent for arrival rates of 24 tows per day, and by 77.8 percent for arrival rates of 44 tows per day. A similar simulation was carried out for UMR lock 25, except that the SPF rule was combined with tow speed control designed to achieve just-in-time (JIT) arrival at the lock. The combination of SPF and JIT resulted in simulated short-run cost savings averaging $255 per barge per lockage (for arrival rates of 18 barges per day). It should be noted that actual implementation of either measure requires real-time traffic management for coordination of speeds and sequencing of tows.

A 2003 report issued by the Center for Transportation Studies at the University of Missouri-St. Louis called for development of a Mississippi River waterway traffic appointment system, and for reexamination of the measures included in the 1999 Corps study (Ronen and Nauss, 2003; USACE, 1999). An appointment system offers another means of prioritizing tows so as to minimize the social cost of congestion. Ships approach-

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ing the Panama Canal, for example, must e-mail or fax ahead for an appointment. They are also offered the option of requesting priority treatment in return for payment of an additional fee. In this way, cargo that would involve the highest delay costs can be moved to the head of the queue.

Several feasible, potentially beneficial nonstructural measures have been omitted from the Corps' screening and evaluation of small-scale measures. In the case of the Corps-sponsored studies on scheduling referred to above, it appears that decision rules for lockage priority could lead to major reductions in delays and costs, at least in the case of high arrival rates (as predicted for the future by the Corps' scenarios). These studies need further development and careful evaluation, but it is surprising that such a long-term program of directly applicable Corps-sponsored research, producing no fewer than nine peer-reviewed papers, was not considered in the feasibility study.

Potential for Nonstructural Measures to Reduce Congestion

In the report from the Phase I NRC committee, the Corps was advised to conduct a "comprehensive review and assessment of nonstructural options for improving traffic management" (NRC, 2001). That report emphasized that benefits to proposed lock construction cannot be evaluated fully until the existing system is operated more efficiently. These concerns were repeated in this Phase II committee's initial report (NRC, 2004a). Since that 2004 report was issued, this committee has reviewed the Volpe report and many other documents and has discussed this issue with the Corps. The conclusion remains the same: review of nonstructural measures has been inadequate. This issue is crucially important for three reasons: (1) major construction projects should not be undertaken when acceptable, less costly, and equally effective nonstructural means can achieve the same end, (2) substantial uncertainty with respect to the volume of future river traffic calls for flexible, incremental approaches, which are typically best achieved through nonstructural measures, and (3) even if major construction is undertaken, effective nonstructural measures will be needed to deal with increased congestion during the construction period.

Many shipping and agribusiness industry representatives argue that significant efficiency improvements in the existing system will be few and hard to find. They credit the practice of industry self-help, and a greater use of the "N-up/N-down rule," as removing most existing inefficiencies. The Corps and the industry appear to agree that the addition of switchboats and additional mooring points will largely exhaust the feasible opportunities for reductions in congestion. This position does not consider the existence of entire categories of nonstructural measures that have been only partially

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examined, especially economic instruments (tradable permits, congestion fees, etc.) and various kinds of scheduling and appointment systems. Some of these measures may be capable of significant, cost-effective reductions of the costs of congestion. If major structural improvements are justified by expected future growth in traffic, judicious use of nonstructural measures could defer the need for some or all of those major improvements, perhaps for decades. Furthermore, these measures could reduce current delays and costs prior to the time when any major construction would be completed.

The costs imposed on farmers and other shippers by the failure to manage this precious national inland waterway resource more efficiently are a matter of concern. As a matter of sound analysis, the benefits of extending locks or other waterway improvements cannot be estimated properly until the beneficial nonstructural measures have been implemented. If construction was started, nonstructural measures would be needed even more, since there would be a reduction in waterway capacity during the decade of construction, requiring still better allocation of the existing resources.

It has been argued that many proposed nonstructural measures for managing traffic have limited relevance to actual conditions on the UMR-IWW. Reasons offered include the complexity and unpredictability of commercial river traffic, configuration of the lock system, hydrologic variability of the river system, and volatility of markets for transported commodities. The challenges associated with implementing nonstructural measures should not be taken lightly. It is important that consideration of any nontraditional management approach include a genuine effort to adapt it to existing conditions, rather than simply rejecting it as unsuited to those conditions. Accordingly, until careful evaluation of all potentially useful measures—preferably based on empirical data—is completed, assertions that nonstructural measures cannot be applied successfully to UMR-IWW traffic cannot be accepted.

Implementing some nonstructural measures for managing waterway congestion could decrease congestion, reduce shipping costs, and use the existing waterway more efficiently. Because the costs of implementing nonstructural measures are low, and because some have positive net benefits, implementation of these measures should be of the highest priority. A comprehensive evaluation of UMR-IWW traffic management alternatives will identify and thoroughly evaluate all plausible measures. The failure to consider and evaluate the prospects of all potentially beneficial nonstructural measures for better managing waterway traffic undermines the conclusions and recommendations regarding proposed structural improvements.

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Measuring Benefits of Improvements

All measures taken to improve the efficiency of navigation, whether structural or nonstructural, are expected to produce economic benefits in excess of the costs. Any measure that meets this test is said to be feasible, in the economic sense, and to result in an increase in the National Economic Development (NED) account. The prediction of costs for proposed measures is relatively straightforward; most elements of cost are calculated through conventional engineering economic procedures. The prediction of benefits, however, is much more challenging.

The Corps' Planning Guidance Notebook (USACE, 2000; see Section IV, Chapter 6) lists the four categories of benefits expected from reducing waterway congestion:

1. Cost reduction benefits
2. Shift-of-mode benefits
3. Shift of origin-destination benefits
4. New-movement benefits

Note that some of these benefits will be positive, but others may be negative (i.e., offsetting positive benefits). The algebraic sum of the four categories is the estimate of total benefits.

Economic Models

In the case of the navigation improvements described in this report, which are generally designed to reduce congestion at specific locks or to reduce transportation cost in other ways, two general approaches to benefit estimation can be considered:

1. A spatial equilibrium model—which reflects grain demands, supplies, prices, and transportation costs—can be used to determine commodity movements on the river and via other transportation modes with and without congestion reduction. Results of this model are then used to calculate each of the benefit components listed above. The model itself accounts for all modal shifts as well as changes in quantities. As noted in the report from the Phase I committee, and in this committee's first report in early 2004, this is the preferred strategy.

2. An empirical transportation demand function can be estimated for each pool and for each commodity group. This demand function, technically a "derived demand for transportation services" may reflect the factors

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described above. However, because the function is estimated from data that may or may not reflect changes of the kind under study, it may not fully capture all responses to congestion reduction. This approach is marginally acceptable, if only because it is an improvement over prior methods of measuring navigation benefits.

At one time, the Corps planned to develop a spatial equilibrium model for the UMR-IWW feasibility study. This model was named the Inland Navigation Excel Spreadsheet Spatial Equilibrium Nascent Concept Execution, or the (in) ESSENCE model. The use of the underlying concepts behind this model was applauded within the NRC Phase I committee report. However, at the time of that review, the model was incomplete, and some aspects appeared to have been misspecified and/or to have been based on hypothetical data. After reviewing the ESSENCE model the Phase I committee report listed suggestions for improvement, and also recommended that an unrevised ESSENCE not be used in the feasibility study. In response to the recommendations in the NRC Phase I committee report, the Corps initiated a research program at its Institute for Water Resources (discussed below) for the purpose of developing improved economic models. Meanwhile, however, the Corps continued its use of the ESSENCE model in the same form reviewed by the Phase I committee. This Phase II committee reviewed the ESSENCE model again in its first report, concluding that "there is no useful role for the ESSENCE model in the restructured feasibility study" (NRC, 2004a, p. 23). To reiterate, the ESSENCE model in its present form serves no useful role in the feasibility study.

The Corps also reintroduced the Tow Cost Model (TCM) as an alternative method of estimating benefits of reduced waterway congestion. The TCM is part of a suite of models that had previously been used for the same purpose as the subsequent ESSENCE model. The Waterway Analysis Model (WAM) simulates conditions and commodity movements on the entire navigation system. The TCM uses these outputs to generate cost-effective configurations of barges, towboats, origins, and destinations. This leads to predictions of tow arrivals at each lock. Congestion at the lock is represented by a separate queuing model (as in the case of ESSENCE). Economic benefits of congestion reduction are then estimated by the TCM. These models were developed by the Corps in the 1970s and have since been updated and modified several times.

The primary limitation of the TCM is its simplistic representation of the demand for waterway transportation. To generalize, the TCM assumes that shipments will be unaffected by rising transport cost (due to increasing congestion) until it reaches the cost of the least cost alternative mode (presumed to be rail shipment). At that point, all traffic is assumed to move

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from the waterway to rail. In economic terms, the TCM assumes that demand for water transportation is perfectly inelastic for prices below the cost of rail shipment and perfectly elastic at that point. In other words, the TCM assumes that shippers will not respond in any way to rising congestion costs until water transportation becomes infeasible; at that point, all shippers will then change modes.

Numerous issues are neglected in this oversimplified representation of economic demand. Even the "boundary conditions" are incorrect (there is no single alternative shipping cost—it depends on rail capacity, proximity of shippers to railheads, proximity of shipper to barge loading points, and so on). In principle, the accuracy of the boundary conditions can be improved by disaggregating shipments and applying the mode separately to each commodity and each origin-destination pair within a commodity grouping. In practice, however, the data needed to support such an analysis may be lacking. It is also questionable that any disaggregation based on shipment characteristics would identify all factors that affect the choice of water transport. Yet even if more realistic boundary conditions could be provided, the assumption of perfectly inelastic demand for all shipping costs below the boundary (alternative cost) remains at odds with reality.

Through the course of this committee's study, several academic and other experts and practitioners in the fields of grain production, shipping, and commercial transportation provided comments regarding grain shipments and multiple end uses, markets, and shipping options available to farmers. These comments indicated a strong consensus that small changes in market prices as experienced by grain producers (driven, for example, by changes in shipping costs) are sufficient to transfer significant amounts of grain from one market to another. This committee concurs with this consensus and further notes that similar factors also influence non-grain shipments. This reality is not represented in any way by a model that assumes unchanging barge movements for all shipping costs below the relevant boundary conditions. The TCM thus produces a result that is a significant, perhaps substantial, overestimate of the benefits of reduced congestion. Any calculations based on the TCM contain no information about actual benefits. **The TCM contains assumptions and functions that do not adequately reflect responses of shippers to changes in shipping costs. It therefore produces results that are of only marginal use in the feasibility study**.

ESSENCE and Tow Cost Model Applications

A Corps guidance memorandum dated August 11, 2004, stated the rationale for continuing to use the TCM. According to the memorandum, the

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Corps recommended that the original ESSENCE model could be used in conjunction with the TCM to conduct a sensitivity analysis with respect to demand elasticity. This memorandum accepted that use for that limited purpose. In implementing this approach, the feasibility study provides three measures of project benefits for each of the barge traffic scenarios:

1. TCM—A presumed "upper bound" on benefits
2. EUB (estimated upper bound)—Benefits calculated by the ESSENCE model, using parameter values selected to produce a high number
3. ELB (estimated lower bound)—Benefits calculated by the ESSENCE model, using parameter values selected to produce a low number

When combined with the five barge traffic scenarios, this approach produces 15 alternative estimates of project benefits for any given configuration of future navigation system infrastructure improvements. Given the long planning period and the considerable levels of uncertainty associated with future values of most key variables, this is a reasonable way to proceed. If benefits could actually be bracketed (by reliable estimates of upper and lower bounds) for each scenario, and if the scenarios were properly designed, a simplified form of risk analysis would be possible.

The strategy, however, is undermined in several ways. As already noted, the scenarios are poorly designed. The TCM result is at least an approximation of the upper bound on the benefits of reduced waterway congestion, but benefit calculations from virtually any set of parameters defined by the ESSENCE model are suspect, and there is no assurance that the values computed by the Corps are above or below the true benefits of reduced waterway congestion. No credible lower bound on the benefits of proposed lock extensions is thus available.

Economic Model Development

The first report of this Phase II committee (NRC, 2004a) encouraged the Corps to develop a spatial equilibrium model, as had the prior Phase I committee report (NRC, 2001). To further illustrate the advice regarding the development of a spatial grain model, this committee's first report included an appendix describing some of the desired features of such a model (NRC, 2004a, Appendix A). Subsequent to issuance of the NRC Phase I committee report, a research program—the Navigation Economic Technologies (NETS) program—was instituted at the Corps Institute for Water Resources to develop a suite of economic models for evaluation of

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inland navigation projects. The initial NETS program plan calls for three tiers of models:

1. International traffic flow model. This model allows for deep draft multiport analysis of exports and imports, facilitating the evaluation of port improvements. It may also be capable of generating port-specific grain export shipments.
2. Regional traffic routing model. This model would, as presently planned, generate a spatial equilibrium picture of commodity movements ultimately exported from U.S. ports (e.g., grain).
3. Microscopic systems model. This suite of methods can generate and route individual shipments through inland waterways, while maintaining consistency with the results of the upper-tier models. These methods could include economic benefit models.

The NETS program is in its early stages, and no firm decisions have been made on the specifics of the models described above. It is possible that these models may collectively satisfy the modeling criteria set forth in Appendix A, although this is not currently known. Thus, although the NETS program holds promise, results from this program have not been used to inform the feasibility study, nor is there any guarantee that the program will be continued or that its results will ever provide meaningful inputs to the policymaking process. The IWR has sought advice and assistance from a broad range of experts, inside and outside the Corps. Because of the IWR's contacts with U.S. universities, there promises to be some degree of participation by researchers from outside the Corps. The intention is to develop credible models that have been subjected to expert review and that are transparent and data driven. A review of this research program was not part of this study or report. The Corps should be credited for initiating this program and for placing it in an organization that is relatively independent of day-to-day project considerations and has ties to the research community beyond the Corps.

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4
Implementation

PREFERRED PLAN

The Corps' feasibility report concludes with a Preferred Plan, which consists of a series of proposals that reflect the results of the more than ten years of planning and investigations. The Plan's principal features are the following:

- **Dual purpose authority.** Although the Upper Mississippi River system has been designated by Congress as a nationally significant ecosystem as well as a nationally significant commercial navigation system, the feasibility study has been conducted thus far for a single, authorized purpose: inland navigation. In order to obtain project authorizations and appropriations and proceed with implementation of the study's recommendations, the Corps requests that ecosystem restoration be added as a second, coequal project purpose. Given the many important relationships among flood management, navigation, and ecosystem restoration, Chapter 2 of this report presents a recommendation that supports the Corps' request for a multipurpose project authority.
- **Small-scale measures**. The plan recommends authorization and immediate implementation of mooring facilities at seven locks and the establishment of federally funded switchboats at five locks, as well as associated mitigation. The $218 million cost of these measures would be borne equally between the Inland Waterways Trust Fund and general funds.
- **Lock construction**. The plan proposes authorization and immediate implementation of seven new 1200-foot locks, plus associated mitigation measures. The $1.66 billion cost of these measures would be shared equally between the Inland Waterways Trust Fund and general funds. The

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plan also proposes the later authorization of lock extensions at five additional locations, subject to a favorable feasibility report (see discussion of adaptive implementation).

- **Navigation study and monitoring**. Authorization is recommended for a continuing program of studies and monitoring, to include the further development of inland navigation economic models, increased collection of data on global grain markets, and so forth. The costs of these studies would be borne equally between the Inland Waterways Trust Fund and general funds.

- **Adaptive implementation of navigation improvements**. The Corps proposes to continue monitoring and analyzing river traffic and markets and to incorporate improved economic models whenever they become available. At the completion of design for each new lock expansion project, a notification report will be prepared that provides the latest data on traffic and markets. If new economic models are developed and accepted, an evaluation report will be prepared that concludes with recommendations to Congress on whether lock construction should proceed or be delayed. Finally, an updated feasibility report will be completed before authorization is sought for the final five lock extensions.

- **Authorization of specific ecosystem restoration projects**. Project-specific authorization is sought for construction of fish passages at four dams and for engineering and design of a fifth passage. Project-level authorization is also sought for dam point control at two locations. The estimated cost is $250 million in federal funds.

- **Request for program authority for ecosystem restoration projects**. Program authority is requested to allow a variety of ecosystem restoration projects to be pursued, subject to favorable project implementation reports. The costs of individual projects will not exceed $25 million, and the total program cost will be limited to $935 million. All initial construction costs are to be borne by the federal government; operation and maintenance, repair, replacements, and related costs will be funded by the federal, state, or local government, depending on project location.

- **Land acquisition**. The plan proposes authorization for the acquisition, from willing sellers, of up to 35,000 acres of land for purposes of improving floodplain connectivity, protecting or enhancing wetlands, protecting and restoring riparian habitat, and other measures. The estimated $277 million cost will be shared 65:35 between the federal government and local sponsors.

- **Adaptive management of ecosystem restoration projects**. The feasibility study identifies the need for adaptive implementation and man-

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agement and discusses a number of elements of an adaptive management program. All ecosystem restoration projects after the first 15 years will require a new feasibility study, which would incorporate the experience and knowledge developed in the first 15 years. For the projects and program proposed for immediate authorization, however, adaptive management would apparently be accomplished through the mechanism of project implementation reports, although details of this process are not provided.

Altogether, the Corps proposes a navigation improvement-ecosystem restoration program that is forecast to cost at least $3.34 billion. Costs of future studies, evaluations, or adaptive management, are not specified separately. Total estimated costs would be borne by the Inland Waterway Trust Fund ($939 million), general federal funds ($2.3 billion), and local sponsors ($97 million).

COMMENTARY AND FUTURE DIRECTIONS

This committee was not requested to provide a recommendation to Congress regarding whether the Preferred Plan should be adopted. This report's focus is not the Preferred Plan per se, but on the feasibility study that led to it. The question addressed herein is thus not whether this plan is the best strategy for the nation, but whether elements of the plan flow logically from the findings of the feasibility study and whether those findings are supported by the data and analyses employed by the Corps. Chapter 3 of this report focuses on technical dimensions of the feasibility study's two primary components: environmental restoration and commercial shipping and economics. This final chapter comments on some issues that do not fit neatly into those two categories, but that will nonetheless affect implementation of the study and progress toward achieving navigation, ecologic, and related goals.

Financing Arrangements

Ecosystem Restoration Cost Sharing

This committee's first report (NRC, 2004a) expressed concern regarding the way in which federal cost-sharing rules would apply to the ecosystem restoration components of the project and recommended that the Corps direct its attention to possible restrictions or constraints that may arise from these rules. In the Preferred Plan, the Corps has argued that most restoration projects are federal responsibilities and eligible for 100

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percent federal funding. Only land acquisition is proposed to utilize cost sharing (35 percent local share), with a total of $97 million in estimated cost allocated to local sponsors.

One purpose of federal cost-sharing policies is to ensure that projects proposed by federal agencies are subjected to a "market test," whereby state and local beneficiaries confirm the value of a project by agreeing to share in the cost. In the case of a complex, integrated, basin-level ecosystem restoration plan, however, this "market test" may not be fully appropriate. A particular project, or class of projects, may have little value to potential local sponsors, yet be essential to the success of the overall restoration program. It is also clear that the history of navigation-related modifications to the river system is the primary cause of the ecosystem degradation addressed by the Preferred Plan. In this context, the Corps' proposal for full federal funding for most restoration projects is reasonable.

Navigation Improvement Cost Sharing

Since passage of the Water Resource Development Act of 1986, the cost of navigation improvements and major rehabilitation has been shared with the Inland Waterways Trust Fund. The trust fund receives revenue from the Inland Waterways User Tax, a $0.20 per gallon fuel tax applicable to commercial navigation. The Inland Waterways User Board meets triennially to make recommendations to the Secretary of the Army regarding disbursement of trust fund revenues. In accordance with existing policy, the Preferred Plan assumes that 50 percent of the cost of navigation improvements, both structural and nonstructural, will be funded by the Inland Waterways Trust Fund. In the Preferred Plan, this amounts to a total projected expenditure of $939 million from the trust fund. The feasibility study contains no analysis of the feasibility or impact of this level of disbursement from the trust fund.

Integration

The Corps faces a set of complex problems in integrating the various federal programs connected with the Upper Mississippi River into a cohesive whole and in developing a navigation and ecosystem restoration plan that would consider the diversity of these programs. Many flood protection levees along the Illinois and Mississippi Rivers were built before the 9-foot navigation project and, when the navigation project was built, served

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as dikes to contain the navigation pool (see Box 4-1). Other levees were constructed as part of federal and local flood control programs and separated the river from the floodplain. Over time, the U.S. Fish and Wildlife Service was authorized to create wildlife refuges along the banks of the Upper Mississippi, and these have been operated independently of the navigation project. In 1986, the Congress authorized the Upper Mississippi River System Environmental Management Program to monitor ecology and to rehabilitate river system habitat.

As proposed, the ecosystem restoration effort represents the summation of many individual projects, each contributing to restoration but not necessarily linked to neighboring projects. This may represent the state of the art, but as project development continues, the Corps may wish to seek methods not only to more closely integrate navigation and ecosystem restoration projects, but also to link them to flood management projects, the refuge system, and efforts to improve water quality in the basin.

Box 4-1
Integration and Interconnections in the Upper Mississippi River and Illinois Waterway

After completion of the Upper Mississippi River 9-foot channel project, the navigation dams maintained river levels higher than they normally would have been during the low-water season, which increased the seepage rate through the levees. Congress authorized one-time payments to the levee districts in compensation for the increased costs. This is an example of operations of one sector (navigation) impacting another sector (floodplain agriculture) in a way that apparently was not considered during planning or included in project costs. In this case, Congress was the ultimate "adaptive manager," addressing the issue of mitigating damages to the levee districts after the navigation dams were in place. Today, planners are expected to use more sophisticated forecasting methods and models and to anticipate effects, not only on other commercial uses of the rivers and their floodplains, but also on natural services and amenities provided by floodplain-river ecosystems.

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Overview

This review of the evolving feasibility study has the nature of a critical appraisal, attempting to uncover deficiencies and weak points. A complete reading of this report will reveal many compliments, as well as criticisms and differences of opinion. If these various reactions are considered together and placed in perspective, it is clear that considerable progress has been achieved and equally clear that much more needs to be done. Table 4-1 may help place some of this report's main points in this larger perspective.

As this report has made clear, designing and conducting a comprehensive and credible feasibility study that incorporates the engineering, economic, environmental, and other dimensions of proposed Upper Mississippi River-Illinois Waterway lock extensions represents a major analytical challenge. The Corps of Engineers has put forth a sustained and considerable effort in conducting its UMR-IWW feasibility study, and the agency is to be credited for broadening and deepening the study in many useful ways. Despite these efforts and advances, however, the April 2004 draft version of the Corps' restructured feasibility study contains some crucial analytical flaws. Several of them are inherited from earlier versions of the feasibility study, and they limit the credibility and value of the study as a useful input into the policymaking process.

The UMR-IWW system supports a variety of economic, ecological, and recreational uses. Many of these uses have important impacts on one another, and many, if not most, of the significant UMR-IWW management decisions made today entail trade-offs between different users. The feasibility study focuses on two key UMR-IWW sectors, commercial navigation and ecosystem restoration. Analyses within these sectors proceed essentially on separate tracks. The feasibility study thus provides little information on how operations in these two sectors affect one another or how future operations in either sector might be constrained in having to accommodate other users of the system. Having said this, however, it bears noting that ecosystem restoration is not an explicitly authorized UMR-IWW project purpose, while the maintenance of a reliable 9-foot channel on the UMR-IWW dates back to the 1930 project authorization. The Corps thus deserves credit for broadening its feasibility study in an effort to accommodate both commercial navigation and ecosystem restoration. The feasibility study also recognizes that the 1930 authorization may lack clarity with regard to twenty-first century management preferences and priorities. The Corps' efforts to seek broader authority for managing the multiple resources of the UMR-IWW are appropriate. The Corps should seek a multiple-purpose planning and operations authority for

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TABLE 4-1 Progress and Areas for Improvement in the Feasibility Study

Past	Present	Near Future
Data and analytical techniques inadequate Corps lacked clear authority for ecosystem management or restoration Result: study was weighted toward navigation expansion (e.g., new Lock and Dam 26 was constructed), while environmental mitigation and monitoring were never fully funded and the Fish and Wildlife Coordination Act report was never finalized	More data are available, making it possible to compare actual traffic data to predictions made 10 years ago; environmental data are available from the EMP, habitat needs assessment report, and so on A commendable attempt to improve analyses was made, but deficiencies remain The Corps requests new authorities for environmental management A staged implementation plan is proposed, increasing the prospects for adaptive management Corps draft feasibility report-EIS is more balanced, but ecosystem management and restoration are only weakly integrated with navigation and flood management considerations	More economic and environmental information will be available; improved models should be available Better, spatially explicit economic models should be available prior to the next decision point Better integration of environmental improvements with navigation and flood management considerations should be demonstrated

NOTE: EMP = Environmental Management Program; EIS = Environmental Impact Statement.

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the UMR-IWW that would allow it to consider and integrate flood management, commercial navigation, and ecosystem restoration.

The economic analysis of commercial navigation also contains flaws. The purpose of economic analysis should be to identify the most efficient strategies for reducing congestion on the river and to determine whether the most efficient strategy provides net benefits to the nation. As acknowledged in the feasibility study, candidate strategies to reduce shipping costs include both structural and nonstructural (including small-scale) measures. Although the restructured feasibility study includes and explores some nonstructural elements for managing waterway congestion, the evaluation of nonstructural measures is incomplete and does not include any adequately analyzed examples. Several promising alternatives are not considered at all. As a result, the study offers little guidance regarding whether nonstructural measures can provide cost-effective reductions in congestion levels.

The economic benefits of lock extensions or replacements were estimated on the basis of five alternative scenarios of future barge traffic, using both the Tow Cost Model (TCM) and the ESSENCE model. The Corps deserves credit for adopting the suggestion from the NRC (2001) Phase I committee report to use scenarios rather than point forecasts. However, the barge traffic scenarios incorporate (1) inadequate treatment of non-grain shipments and (2) grain shipment scenarios that, taken together, are biased in the direction of future growth. The non-grain shipments are of particular interest since they account for approximately half of all barge traffic today; yet forecasts are based on data more than a decade old and do not consider recent or plausible future trends. To predict grain traffic shipment levels reliably, alternative uses of land, demands for grain, and destinations and shipping routes have to be analyzed; little of this was done. The limitations of the economic models (TCM and ESSENCE) are described herein and in this committee's first report (NRC, 2004a). Although application of the TCM produces an approximate upper bound on benefits of proposed lock extensions, no credible lower bound is presented in the study. The ESSENCE model provides no useful output. The upshot of these shortcomings is that economic justification of proposed lock extensions on the UMR-IWW has not been established by these models.

The ecological portion of the restructured study—although representing a large advance over earlier versions of the feasibility study—does not define a clear, science-based framework for implementation, monitoring, and evaluation. The feasibility study includes an extensive list of possible restoration measures, many of which could help promote restoration. Theories of river science and research, conducted on the UMR-IWW and elsewhere, point to the overriding importance and priority of restoring

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some degree of fluvial processes in order to promote ecosystem restoration. Rather than focusing on how they can help restore natural processes, however, the principal measure for ranking alternatives is "area affected"—a metric that is not well correlated with ecosystem function. Proposed restoration measures should be related more clearly to overarching scientific theories of river science and restoration.

Although the flaws and weaknesses summarized in this report are serious and of concern, they must be weighed in light of the challenges posed by this study. River science theories and research from the Environmental Management Program (EMP) provide useful guidance, as do river management efforts conducted elsewhere, but ecosystem restoration on the scale of the UMR-IWW is essentially unprecedented. Progress toward adaptive management on the UMR-IWW will require support and participation from parties beyond the Corps, including the U.S. Congress, other agencies, and river system users. The Corps has devoted a considerable effort to expanding and improving the study, especially in the last several years. One helpful outcome of this effort has been the development of a Preferred Plan that explicitly incorporates incremental implementation, based on continuing data collection, improved modeling techniques, and evaluation. If this plan is carried out as proposed in the restructured feasibility study, some of the problems noted in this report could be addressed through the application of methods of adaptive management. If so, the long-term prospects for the UMR-IWW could be a system that is managed and balanced in a way that provides even greater benefits to the nation.

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Appendix A

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TABLE A-1 Mississippi River and Illinois Waterway System - Traffic Delays per Tow Annual Average (hours)[a]

System	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Mississippi River												
Upper St. Anthony	0.03	0.03	0.03	0.02	0.01	0.03	0.03	0.02	0.01	0.03	0.03	0.03
Lower St. Anthony	0.03	0.06	0.06	0.03	0.03	0.02	0.04	0.03	0.02	0.03	0.04	0.02
Lock and Dam 1	0.05	0.07	0.16	0.15	0.19	0.18	0.17	0.03	0.02	0.04	0.03	0.05
Lock and Dam 2	0.73	0.58	0.60	0.49	0.39	0.53	0.55	0.56	0.56	0.55	0.48	0.62
Lock and Dam 3	0.70	0.57	0.59	0.52	0.45	0.51	0.52	0.47	0.42	0.47	0.42	0.53
Lock and Dam 4	0.51	0.45	0.39	0.39	0.29	0.39	0.40	0.42	0.40	0.52	0.41	0.38
Lock and Dam 5	0.44	0.46	0.50	0.44	0.42	0.41	0.56	0.45	0.39	0.45	0.40	0.42
Lock and Dam 5a	0.42	0.42	0.41	0.46	0.33	0.44	0.43	0.49	0.42	0.50	0.45	0.41
Lock and Dam 6	0.67	0.71	0.64	0.70	0.46	0.63	0.73	0.68	0.60	0.66	0.61	1.05
Lock and Dam 7	0.83	0.70	0.68	0.64	0.55	0.60	0.67	0.70	0.75	0.66	0.69	0.86
Lock and Dam 8	0.89	0.81	0.89	0.60	0.62	0.89	0.96	0.88	0.75	0.83	0.77	0.89
Lock and Dam 9	0.54	0.47	0.57	0.39	0.46	0.60	0.60	0.65	0.70	0.70	0.76	0.65
Lock and Dam 10	0.71	0.51	0.69	0.51	0.39	0.81	0.89	0.95	0.67	0.76	0.73	0.82
Lock and Dam 11	1.79	1.39	1.19	0.74	0.72	1.25	0.97	0.96	0.84	0.95	0.94	0.95
Lock and Dam 12	1.31	1.32	1.24	0.70	0.57	0.98	1.13	1.01	0.82	1.06	0.87	1.30
Lock and Dam 13	1.16	1.52	1.25	0.95	0.71	1.32	1.26	0.82	0.70	1.00	0.99	0.97
Lock and Dam 14	3.97	1.43	1.19	0.89	0.93	1.66	2.40	2.75	2.53	3.91	2.57	2.48
Lock and Dam 15	3.11	2.53	2.78	2.09	1.10	2.56	3.23	1.68	1.89	2.75	1.48	2.83
Lock and Dam 16	1.91	1.83	2.20	2.71	0.92	1.60	1.67	1.24	1.55	1.78	1.27	2.04
Lock and Dam 17	3.91	1.85	2.26	5.14	0.88	2.25	1.81	1.57	2.16	2.15	1.55	1.76
Lock and Dam 18	3.07	2.89	2.62	2.88	0.97	3.17	2.53	1.47	1.25	1.80	1.60	2.11
Lock and Dam 19	1.01	0.88	1.11	1.07	0.70	0.82	0.85	0.77	0.70	0.74	0.81	0.79
Lock and Dam 20	5.31	1.97	2.65	5.16	0.99	2.25	3.43	1.76	1.71	2.17	2.72	2.38
Lock and Dam 21	2.35	2.07	2.33	1.90	1.05	3.15	3.02	1.73	1.68	1.94	2.21	2.65
Lock and Dam 22	5.06	3.06	4.21	3.43	1.76	6.62	8.32	3.53	2.90	3.83	3.64	5.20
Lock and Dam 24	6.00	2.94	4.16	3.06	1.48	5.05	4.79	3.03	4.60	2.92	2.71	4.10
Lock and Dam 25	3.76	2.86	6.51	2.93	2.68	5.78	3.94	3.07	4.82	3.81	3.23	5.71
Melvin Price (26)	7.28	1.47	1.73	1.04	2.35	5.25	0.80	0.61	0.66	8.37	2.03	3.97
Lock and Dam 27	5.17	4.30	8.32	1.26	6.31	4.49	14.42	39.09	2.33	6.51	0.96	0.79

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TABLE A-1 (continued)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Illinois Waterway System												
LaGrange	1.47	0.52	1.17	0.22	1.51	3.54	6.32	3.67	2.11	2.79	4.61	2.47
Peoria	0.84	0.50	1.10	0.13	1.40	2.23	2.48	2.19	1.04	1.30	1.62	1.21
Starved Rock	0.85	0.91	0.84	1.12	1.54	1.70	0.95	1.38	1.16	1.29	1.35	1.53
Marseilles	1.35	1.14	1.24	1.35	1.60	2.18	1.02	1.61	1.52	1.68	1.72	2.02
Dresden Island	0.77	0.77	0.74	0.68	1.08	2.47	0.79	0.87	1.11	1.01	1.04	1.36
Brandon Road	0.93	0.89	0.94	1.24	1.67	2.38	0.95	1.19	1.34	1.28	1.45	1.73
Lockport	1.08	1.02	1.09	1.30	1.91	2.69	1.10	1.35	1.81	1.38	1.99	1.73
Thomas J. O'Brien	0.04	0.05	0.07	0.06	0.08	0.07	0.08	0.07	0.08	0.05	0.06	0.05

[a] Average delay = average time from arrival to start of lockage. SOURCE: USACE, 2004.

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Appendix B

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Appendix C
Committee Members and Staff Biographies

COMMITTEE MEMBERS

JOHN J. BOLAND (*chair*) is a professor emeritus in the Department of Geography and Environmental Engineering at Johns Hopkins University. His fields of research include water and energy resources, environmental economics, and public utility management. Dr. Boland has studied resource problems in more than 20 countries, has published more than 200 papers and reports, and has coauthored two books on water demand management and three others on environmental management issues. Dr. Boland is a registered professional engineer. He has served on several National Research Council (NRC) committees and boards, including the Water Science and Technology Board, of which he was a founding member (1982) and past chair (1985-1988). He is a life member of the American Water Works Association and past chairman of its Economic Research Committee. Dr. Boland received his Ph.D. degree in environmental economics from Johns Hopkins University.

PATRICK BREZONIK is a professor in the Department of Civil Engineering and the past director of the Water Resources Center at the University of Minnesota. Prior to his appointment at the University of Minnesota, Dr. Brezonik was a professor of water chemistry and environmental science at the University of Florida. His fields of research include biogeochemical processes in aquatic systems, with an emphasis on the impacts of human activity on water quality and element cycles in lakes and watersheds. He is a past member of the NRC's Water Science and Technology Board and of several NRC committees, including chair of the Committee to Revitalize Education in the Field of Limnology. He received his B.S. degree in chemistry from

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Marquette University and his M.S. and Ph.D. degrees in water chemistry from the University of Wisconsin-Madison.

ROBERT K. DAVIS has most recently been associated with the Institute of Behavioral Science at the University of Colorado. He is the former head of the Economic Staff in the Office of the Secretary of the U.S. Department of the Interior. His fields of research include natural resource economics, environmental policy analysis, water resources planning, and methods of benefit-cost analysis. His Ph.D. thesis is widely considered the first publication on contingent valuation, a method in wide use today to quantify environmental benefits and damages. Dr. Davis has served as an adviser to foreign governments, has served in faculty positions at several universities, and has served on the staff of Resources for the Future. Dr. Davis received his B.S. and his M.S. degrees from Ohio State University and his M.P.A. and Ph.D. degrees from Harvard University.

LEO M. EISEL is a principal engineer at Brown and Caldwell in Denver, Colorado. Dr. Eisel has more than 29 years of experience with water rights and water resources. He is the former director of the Illinois Environmental Protection Agency, the Illinois Division of Water Resources, and the U.S. Water Resources Council. He is also a past president of McLaughlin Water Engineers in Denver. Dr. Eisel has served on several National Research Council committees and has served as a member of the NRC's Water Science and Technology Board. He received his Ph.D. degree in engineering from Harvard University.

STEPHEN W. FULLER is a professor in the Department of Agricultural Economics at Texas A&M University. Dr. Fuller's fields of research focus on transportation, marketing, and international trade issues, with an emphasis on the economics of Mississippi River waterway transportation. Dr. Fuller served on the NRC Committee on Freight Transportation Needs for the 21st Century. He is author of 280 refereed journal articles and reports that focus on agricultural transportation and marketing issues. Dr. Fuller has been honored five times by the Transportation Research Forum for his research by receiving the Outstanding Paper in Rural Transportation Award. Dr. Fuller received his B.S. and M.S. degrees in agricultural economics and his Ph.D. degree in economics, all from Kansas State University.

GERALD E. GALLOWAY is vice president of the Enterprise Engineering Group at the Titan Corporation in Arlington, Virginia. Dr. Galloway is a former secretary of the U.S. Section of the International Joint Commission. Dr. Galloway has served as a consultant on water resources engineering and

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management issues to the Executive Office of the President, the World Bank, the Organization of American States, the Tennessee Valley Authority, and the U.S. Army Corps of Engineers. Dr. Galloway is a former dean of the Academic Board (chief academic officer) of the U.S. Military Academy. Dr. Galloway holds masters' degrees from Princeton, Penn State, and the U.S. Army Command and General Staff College. Dr. Galloway received his Ph.D. degree in geography from the University of North Carolina.

LESTER B. LAVE (IOM) is the Harry B. and James H. Higgins Professor of Economics and University Professor at Carnegie Mellon University. His fields of research include applied economics and public policy, safety goals for dams and other structures, and quantitative risk assessment. Dr. Lave chaired the NRC Committee to Review the Upper Mississippi River-Illinois Waterway Navigation System Feasibility Study. He is a member of the U.S. Environmental Protection Agency Science Advisory Board and the former president of the Society for Risk Analysis. Dr. Lave received his Ph.D. degree in economics from Harvard University.

KARIN E. LIMBURG is an associate professor at the College of Environmental Science and Forestry at Syracuse University. Her fields of research focus on the Hudson River estuary in eastern New York State. Dr. Limburg teaches a course in fisheries biology and is a co-convener of a seminar series in interdisciplinary courses in watershed ecology. She received her A.B. degree from Vassar College in ecology-conservation and biology, her M.S. degree from the University of Florida in systems ecology, and her Ph.D. degree from Cornell University in ecology and evolutionary biology.

ELIZABETH A. RIEKE is the Lohontan Basin area manager for the U.S. Bureau of Reclamation in Carson City, Nevada. Ms. Rieke is a former director of the Natural Resource Law Center, University of Colorado School of Law, and a former assistant secretary for water and science in the U.S. Department of the Interior. She has served as an associate (1987-1989) and as a partner (1989-1991) with the law firm Jennings, Strouss & Salmon. Ms. Rieke received her B.A. degree from Oberlin College and her J.D. degree from the University of Arizona.

SOROOSH SOROOSHIAN (NAE) is a distinguished professor and the director of the Center for Hydrometeorology and Remote Sensing in the Department of Civil and Environmental Engineering at the University of California, Irvine. His fields of research include surface hydrology (with an emphasis on precipitation runoff modeling), the hydrology of arid and semi-arid regions, and related water resources management issues. He has served

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on several NRC committees, including a six-year term as the chair of the NRC Global Energy and Water Cycle Experiment (GEWEX) Panel. Dr. Sorooshian was elected to the National Academy of Engineering in 2003. Dr. Sorooshian received his B.S. degree from California State Polytechnic University and his M.S. and Ph.D. degrees from the University of California, Los Angeles.

RICHARD E. SPARKS is the director of the Illinois Water Resources Center at the University of Illinois, Urbana-Champaign. Dr. Sparks' fields of research include biological monitoring for pollution control; restoration of degraded aquatic ecosystems; and ecology of large floodplain rivers. He is a member of the American Fisheries Society, the Ecological Society of America, and Sigma Xi. Dr. Sparks was a member of the NRC's Committee on Aquatic Restoration and Committee to Assess U.S. Army Corps of Engineers Water Resources Project Planning Procedures. He received his B.A. degree from Amherst College, his M.S. degree from the University of Kansas, and his Ph.D. degree in biology from the Virginia Polytechnic Institute and State University.

STAFF

JEFFREY W. JACOBS is a senior program officer at the National Research Council's Water Science and Technology Board. Dr. Jacobs' research interests include policy and organizational arrangements for water resources management and the use of scientific information in water resources decision making. He has studied these issues extensively both in the United States and in mainland Southeast Asia. Since joining the NRC in 1997, he has served as the study director of 14 NRC committees. 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.

JOSEPH R. MORRIS is a senior program officer with the National Academies' Transportation Research Board (TRB). On the staff of TRB's Studies and Information Services Division since 1983, Mr. Morris has participated in studies of freight transportation, highway safety, transportation finance, highway design standards, and transportation and air quality. He received his B.A. from Oberlin College, his master of city and regional planning degree from Harvard University, and his M.S. degree from the University of Chicago.

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