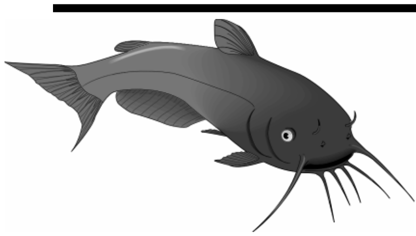
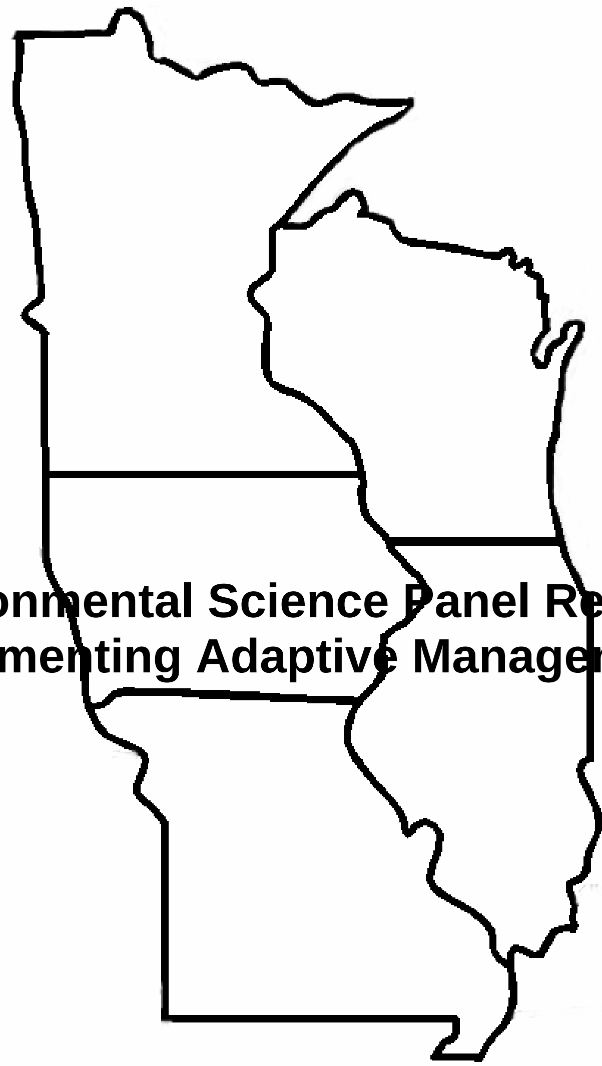
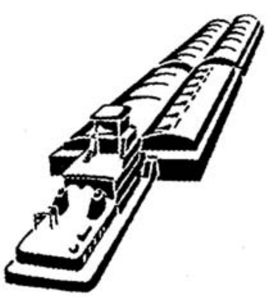
Upper Mississippi River System Navigation and Ecosystem Sustainability Program





Environmental Science Panel Report: Implementing Adaptive Management



August 2006

Rock Island District
St. Louis District
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US Army Corps of Engineers®

Upper Mississippi River System
Navigation and Ecosystem Sustainability Program

NESP ENV Report 2
August 2006

Environmental Science Panel Report: Implementing Adaptive Management

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Executive Summary

Science Panel Purpose

The Navigation and Ecosystem Sustainability Program (NESP) Science Panel was convened to provide scientific expertise needed for adaptive management of the Upper Mississippi River System (UMRS). The short term (FY 05) objectives for the Panel were to review the state of information in the functional areas described below, and make recommendations for implementing adaptive river ecosystem management. Specifically, in this report the Science Panel presents an approach to river managers and stakeholders for integrated ecosystem management and restoration project planning and "on the ground implementation" that addresses environmental objectives at appropriate spatial and temporal scales. The report focuses largely on project-specific restoration actions, rather than objectives of restoration per se, since objectives particularly at the system-scale are still being formulated. The Science Panel recommends a science framework across six functional areas: (1) refining and clarifying ecosystem objectives, (2) developing evaluation criteria outcomes including ecosystem services; (3) evaluating and sequencing proposed ecosystem restoration projects; (4) monitoring, including selection of response variables appropriate to different scales; (5) evaluating relevant ecological indicators, metrics and outcomes for an UMRS ecosystem condition report card; and (6) integrating ecological models and using information technology to facilitate the adaptive management process.

Science Panel Progress

During FY 05, the Science Panel had several full team meetings, workshops for most functional areas, and began interacting with project teams. During seven Panel meetings, the group became familiar with the NESP and the requirements of this large restoration program. The Science Panel engaged a variety of stakeholders and cooperators to better understand their science needs.

Workshops have been an effective way to gather information and put it to use in the Panel setting. The Project Sequencing Team interacted with the Environmental Management Program System Ecological Team on project evaluation and sequencing criteria. The Report Card Team invited experts from the Everglades and Chesapeake Bay restoration programs to gain insight into their experiences and thoughts on the UMRS programs. The Modeling team sponsored a workshop to assess the other teams' modeling requirements, in addition to reviewing available models and brainstorming future modeling approaches with the rest of the Panel. The Ecosystem Services Team participated in a workshop with The Nature Conservancy and others investigating methods for identifying and valuing ecosystem services. Collaboration with stakeholders on Goals and Objectives occurred previously, so refinement of the objectives has proceeded within the Panel and through interactions with reach and pool-scale project teams.

Recommendations

Science Panel work groups associated with each functional area (see above) developed a chapter in the Science Panel report and we authors/editors have excised the following recommendations for river managers, stakeholders, and decision makers to consider.

General Recommendations

The Science Panel strongly recommends active adaptive management to advance learning and improve future project development.
There have been many lessons learned through passive adaptive management over time (i.e., learning from experience), but a more rigorous active adaptive management program (i.e., sequencing projects and monitoring for learning) is preferred. Restoration projects can become learning opportunities by incorporating an experimental technique or technology, being part of a larger experimental design, and by incorporating effective monitoring. Exploiting these learning opportunities will result in fundamental knowledge gains, improved design criteria for future projects, and in widely adopted management innovations.

The Science Panel should provide technical support to the River Council, River Teams, and Project Delivery Teams.

The Science Panel recommends that the Corps develop a system-scale Project Delivery Team.
A team to support system-scale objectives and restoration activities is needed to implement ecosystem restoration. A system-scale ecological team can support the iterative steps of planning, implementation, monitoring, assessment and learning, and improved action typical of adaptive management. A system-scale PDT would function as a scale-up of individual PDTs that addresses the unique challenges and opportunities that exist at the ecosystem-wide scale in the context of adaptive management.

A decision support system should be created to assist planning and info management.
A decision support system should be developed using the ecosystem objectives matrix and a family of ecosystem models described by the Science Panel. This decision support system will assist in tracking progress for project objectives, management and restoration measures applied, areas affected, project information, performance indicators, monitoring activities, monitoring results, ecosystem services affected, and lessons learned. The decision support system will contain a geographic information system (GIS) database to enable visualization and analysis of the spatial arrangement of ecosystem conditions, projects, and management measures. The decision support system will need to be made available to project teams, resource managers, and decision-makers via the Internet.

The NESP partnership must succinctly state their restoration philosophy (e.g., protect the best, restore the rest).
The Science Panel should assist the River Council in review of the science and philosophy of ecosystem restoration to identify a preferred restoration approach. With more clear definition of the partners' restoration philosophy, the Science Panel can review proposed projects forwarded by River Teams according to ecological criteria consistent with the restoration philosophy, and consider their contribution to adaptive management. The Science Panel can then forward a strategy for sequencing projects to the Corps of Engineers for coordination with stakeholders to consider in the context of additional issues related to funding, real estate, construction sequencing, etc.

Goals and Objectives

Clearly focused and quantitative objectives are central to adaptive ecosystem management.
UMRS natural resource managers have made good progress toward unambiguously defining the desired future conditions of the river ecosystem. Goals and objectives for condition of the

river ecosystem were earlier developed by stakeholders and refined by the Navigation Study Science Panel. The Science Panel Goals and Objectives work group further refined the list of objectives during its most recent deliberations. Quantitative ecosystem objectives at specific project and river reach or navigation pool scales should be set by project teams and stakeholders with assistance from the Science Panel, if needed. Ecosystem objectives should logically relate to higher level ecosystem goals, to the conceptual model of the river ecosystem, and to indicators, monitoring activities, management actions, and ecosystem services.

Project Delivery Teams should develop quantitative objectives for projects.
This Science Panel re-evaluated and refined the UMR-IWW System Navigation Feasibility Study Science Panel's list of 81 ecosystem objectives, down to 45 objectives to achieve greater clarity. It refined the structure for relating system-wide to site-scale objectives and to make objectives more practical and quantitative. It is recommended that these 45 ecosystem objectives remain fairly broad. They are intended to guide project teams to define quantitative objectives for project areas.

Decision support tools centered around ecosystem objectives are recommended.

The River Council should adopt a set of system level objectives.
Most of the ecosystem objectives identified by the partnership to date relate to the river reach, navigation pool, or project area scales. Objectives at these smaller scales may combine to attain system-wide objectives or system-wide objectives may have to be attended to differently than objectives at smaller scales. The Science Panel should work with the River Teams and the River Council to develop a quantitative set of ecosystem objectives at the system-wide scale

Ecosystem Services

River managers and stakeholders should understand and adopt a set of ecosystem services in support of project evaluation.
The Science Panel report identifies a number of ecosystem services whose values are clearly recognized by the broader scientific community. The UMRS stakeholders need to review these services in order to determine which should be used for evaluating "balance" among ecosystem, economic, and social facets of the river system, the allocation of ecosystem restoration funds, and then tracking progress in attaining project and river ecosystem objectives. The identification of important ecosystem services provided by the UMRS is the first step toward eventual inclusion of this knowledge into long-term river management decision making. Quantifying and valuing ecosystem services should be incorporated into decision-making for river management and restoration.

UMRS stakeholders should understand and adopt a valuation process for each selected river ecosystem service.
Once important UMRS ecosystem services are identified and selected, each service should be the subject of a review of current measurement or quantification methods. These methods for quantifying and valuing ecosystem services have not had widespread application testing, so experts, many from the international science and economics communities, will need to be invited to advise the UMRS partnership on experience gained on other river systems. The methods selected for quantifying and valuing the services must be developed objectively, to provide consistency across projects and river reaches and be acceptable to all river stakeholders.

Report Card

Introduce the concept and utility of an ecosystem condition report card to stakeholders and the public.
A report card needs to be developed to periodically inform decision-makers and the public about the condition of the UMRS ecosystem. The report card should provide a way to interpret the results of complex scientific investigations and monitoring in a concise, easy-to-understand format. Recommended format will compare values of selected indicators over time, and give partner agencies and stakeholders a clear summary of progress toward goals and objectives for condition of the ecosystem. The Science Panel will engage stakeholders and the public in the indicator selection process using a draft set of indicators based on previously articulated objectives for condition of the river ecosystem.

Integrate other Science Panel products to assure development and implementation of an adaptive management framework for the UMRS.
In the adaptive management process, key points requiring Panel input will occur at the problem assessment, planning/design, monitor, evaluate, and adjust steps. Recommended key products for progress in those steps include conceptual models that facilitate communication among stakeholders, predictive models to assist project planning and evaluation, design of monitoring plans, and an ecosystem report card that aggregates monitoring results for decision-makers and stakeholders.

Further develop indicator lists for use by different audiences at specific scales to communicate information on ecosystem status from the project to system-scale.
We suggest that one static set of report card indicators will not be appropriate for all audiences in the UMRS partnership. Also, varying levels of technical sophistication among stakeholders will likely dictate different approaches for communicating condition of the river ecosystem at multiple scales.

Sequencing

Use criteria for project evaluation developed by the Science Panel and the Environmental Management Program System Ecological Team.
The Evaluation and Sequencing work group developed project evaluation criteria within seven areas of consideration:

- Ecological merit and benefits
- Attention to restoration of natural processes and features
- Benefits over multiple scales
- Critical habitat gains
- Sustainability
- Contribution to learning through monitoring and experimentation
- Compatibility with existing plans

Sequence demonstration projects to evaluate, refine, and reduce uncertainty related to ecosystem restoration actions early in the Program.
The current state of knowledge of river ecosystem restoration varies among project types and management actions. Restoration actions that are well understood and proven to be effective can be implemented at a faster rate because the planning and design can proceed expeditiously. Restoration actions that are less well-understood, or novel, will need to be more fully evaluated through the

adaptive management process. There are many management actions for which the physical responses are well-understood while the biological responses remain uncertain. Some ecosystem project types and management actions should be selected for implementation specifically to learn through careful experimental design, monitoring, and evaluation.

Monitoring

The Science Panel should work with Project Delivery Teams and River Teams to develop project monitoring plans at multiple scales.
Evaluations of projects and management actions are needed to ensure that they produce the desired local effects, determine the spatial extent of those effects, and determine how long they last. The Science Panel will provide general guidance for the kinds of monitoring that should be considered to evaluate project effects. As new projects are proposed, the Science Panel will work with the PDTs and River Teams to determine which projects are the best candidates for extensive evaluation. The PDTs should develop initial monitoring plans for these projects. The Science Panel will review the plans and help the PDTs revise them as needed to ensure that they are scientifically appropriate for evaluating project effects and larger-scale effects where appropriate.

The Science Panel should develop recommendations for a system-scale monitoring plan.
Evaluation of progress in achieving goals for system-wide restoration will require monitoring at the system-scale. The system-level response cannot be determined only through local project evaluations. The Science Panel, in cooperation with River Teams, should develop a large-scale monitoring plan for consideration by the River Council.

The Science Panel should help develop monitoring plans for demonstration projects with Project Development Teams.
Restoration of the UMRS will derive from the combined results of various individual projects whose effects overlap and interact. The Science Panel should assist with development of designs and monitoring plans for multiple projects that evaluate project interactions where possible and that determine the overall effect of a combination of projects at the pool or reach scale. Designs should consider features such as project sequencing, collection of baseline information, synergy among projects, and the marginal effects of adding more projects or project features.

Monitoring should build on and interface with the existing databases.
A better understanding of UMRS ecosystem functions and response to management actions will lead to more effective approaches for sustaining both navigation and environmental benefits. Increased understanding derives from collection, analysis, and interpretation of data, reporting, further experience, and synthesis of learning. A wide variety of extensive data sets are already available for the UMRS. Monitoring and analysis activities should make effective use of existing data whenever possible in designing projects and monitoring plans. Any new data collected should be managed in ways that allow those data to build on existing data sets and that allow easy access to both old and new data by managers, researchers, and administrators.

Modeling

Integrate ecological modeling with project planning, monitoring, evaluation, and decision-making.
UMRS Managers, PDTs, and stakeholders should incorporate conceptual, physical and ecological models into their management and restoration activities, because model development, implementation, and refinement through adaptive management can foster collaboration and learning among model builders, stakeholders, and partners**.** Appropriate models should be used to help design projects and monitoring programs (e.g., determine sample design, evaluate alternative plans, address scale issues, and evaluate impacts of variability and uncertainty). Models need to be developed and used appropriately to evaluate project alternatives and estimate probable outcomes of specific management and restoration actions at the project, pool, reach, or system scale. The modeling and integration group of the Science Panel should provide guidance concerning the selection of ecological and physical models appropriate for specific management and restoration activities. Models should be regularly updated with knowledge gained through monitoring and assessment as well as experience obtained from using the models.

Ensure quality and defensibility of all modeling tools.
Models used in support of management and restoration actions must be scientifically and technically defensible. They will have to adhere to quality control and quality assurance standards established by the Corps of Engineers. These standards and practices would address critical model assumptions, scale, articulation, resolution, accuracy, model structure, governing mathematics, estimation of model inputs, interpretation of model results, and characterization of uncertainties and model performance.

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1 Introduction

A. Science Panel Purpose

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B. Science Panel Organization

The Science Panel reviewed the recommendations of the UMR-IWW System Navigation Feasibility Study Science Panel (Lubinski and Barko 2003) and formed work groups around the major components of adaptive ecosystem management. The work groups (often alternatively referred to as "Teams" in this report) were formed to address:

1. Goals and Objectives
2. Project Evaluation and Sequencing
3. Report Card
4. Ecological Services and Outcomes
5. Monitoring
6. Modeling

The Panel agreed that restoration plans should be based on clearly stated objectives for the condition of the Upper Mississippi River System (UMRS) ecosystem. Goals and objectives, ranging from site to system scales, are a central component of adaptive ecosystem management (figure 1). Other subjects of the Science Panel activities range from providing scientific guidance on technical topics to assisting river managers with identifying appropriate ways to convey information about condition of the river ecosystem to the public.

C. Science Panel Work Groups (Teams)

1. Goals and Objectives

The Science Panel Goals and Objectives Team was charged with refining, clarifying, and integrating the UMRS ecosystem goals and objectives provided by stakeholders. The ecosystem objectives are central to adaptive ecosystem management and are intended to guide river restoration and management efforts

2. Ecosystem Services

The Ecosystem Services Team introduced the Science Panel and the Corps to the concepts of ecosystem services, and developed recommendations for incorporating ecosystem services into the adaptive management process

3. Project Evaluation and Sequencing

The Project Evaluation and Sequencing Team reviewed Corps of Engineers environmental planning processes for the UMRS Environmental Management Program. The Environmental Management Program approach was refined by considering ways to evaluate local and system-wide benefits of proposed restoration projects through an assessment of specific ecological criteria

4. Monitoring

The Monitoring Team developed guidance on how to monitor and evaluate the effectiveness of ecosystem restoration efforts at multiple scales and to improve long term efficiency of the program. The monitoring Team was charged to work closely with the other Science Panel teams to assure information needed to model and evaluate outcomes, better understand the system, learn from experimental projects and communicate ecosystem conditions.

5. Report Card

The Report Card Team identified potential indicators and monitoring approaches to track condition of the UMRS ecosystem. Indicators can span multiple scales and are frequently difficult to interpret or quantify at large scales. Multiple lines of evidence can provide evidence for trends in condition of the river ecosystem.

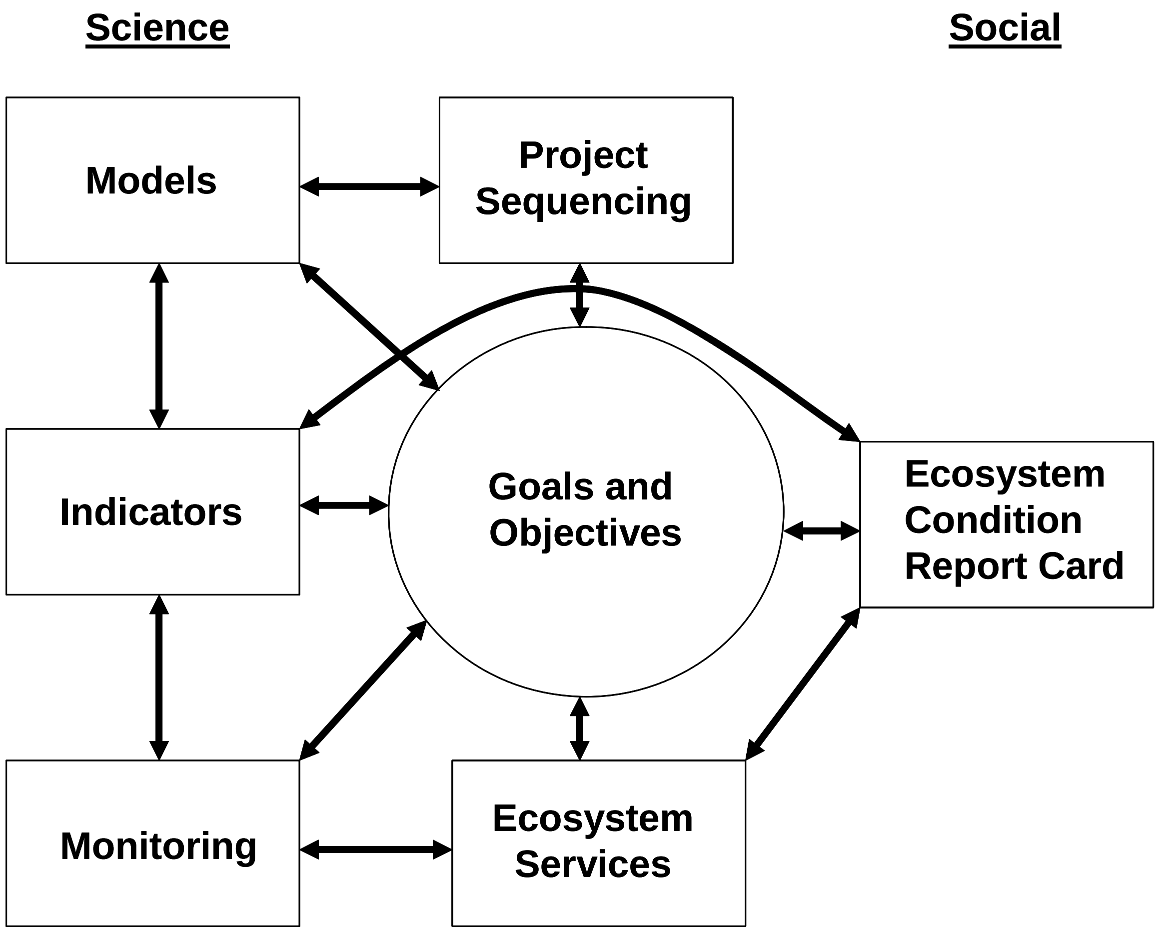

Figure 1. Environmental goals and objectives are central to adaptive ecosystem management and to the structure of the Science Panel work groups. Environmental objectives should be the linking variable in a decision support system to aid UMRS ecosystem management and restoration planning, tracking, and evaluation.

6. Modeling and Integration

The Modeling an Integration Team identified modeling approaches appropriate to adaptive management of the UMRS ecosystem. Conceptual, physical, numerical process-based and empirical ecosystem models were reviewed for use in different phases of the adaptive management process.

D. Institutional Interactions With the Science Panel

The NESP, as proposed, is an ambitious program that has many state, Federal, and non-governmental partners. The program is structured in a spatial and administrative hierarchy (figure 2) with Corps Project Delivery Teams (PDT) working with local field level natural resource managers and the public working with Federal, state and private land owners to plan and implement ecosystem management and restoration projects. Interagency River Teams exist at the Corps District level to compile local environmental management needs and opportunities and administer program management within the Corps of Engineers District boundaries for the St. Louis, Rock Island, and St. Paul Districts. These teams approximately represent the major river reaches, which have different problems and opportunities. A regional committee, the River Council, has been proposed to integrate UMRS ecosystem management and restoration across agency programs. The Science Panel is viewed as adjunct to provide scientific guidance to all levels of the institutional hierarchy.

The Science Panel will initially make recommendations for a set of programmatic guidelines for a robust adaptive management plan. Some of the programmatic guidance will be in the form of tools for PDTs. This structure will be available to the PDTs to organize their projects and insure they address important restoration and management criteria. The Science Panel will work with project team monitoring plans to assure that they fit into a system framework. Modelers will integrate local results into tools that can help estimate outcomes for future applications of similar measures.

The Science Panel provides guidance at the reach or system scales that can be used by River Teams and PDTs to more effectively operate at the project or pool scale. The adaptive ecosystem management process for the UMRS has several steps where Science Panel and PDT interaction is useful (figure 3).

E. System Level Planning

UMRS stakeholders represent a society with a diverse group of interests, occupying communities distributed among 1,200 miles of river and throughout a 190,000 square mile river basin. Stakeholder interests are frequently local, site-, and subject-specific. Management agencies are fragmented; structured around individual missions, jurisdictions and resources. A myriad of interagency work teams and standing committees have been active in UMRS policy and management for many years. State and Federal fisheries and wildlife mangers who established the Upper Mississippi River Conservation Committee in 1943 have long recognized the need for system-wide river management. The Science Panel recognizes the need for a system level tools that can help structure adaptive ecosystem management based on scientific principals.

The Corps of Engineers uses integrated, interdisciplinary PDTs to plan and implement projects. Ecosystem restoration activities system-wide need to be planned and executed at larger geographic scales than individual projects. Planning for the NESP will range from planning projects at the local scale to navigation pool and river reach scales to system-wide planning. System-scale planning and implementation is presently not associated with an institutional support element in the same way that PDTs are associated with individual projects. Tools and teams are needed to execute the ecosystem planning and implementation steps at the system-wide level.

Institutional organization is needed to conduct system-wide adaptive ecosystem management. Institutional mechanisms are needed to ensure that the iterative steps of adaptive ecosystem management; planning, implementation, monitoring, evaluation, learning, and adaptation are successfully accomplished. Therefore, the Science Panel recommends that teams and tools be created that address the challenges of addressing system-wide ecosystem planning. The Science Panel Regional Support Team is an example of one such team. Additional responsibilities of the system-level teams are described later in this report.

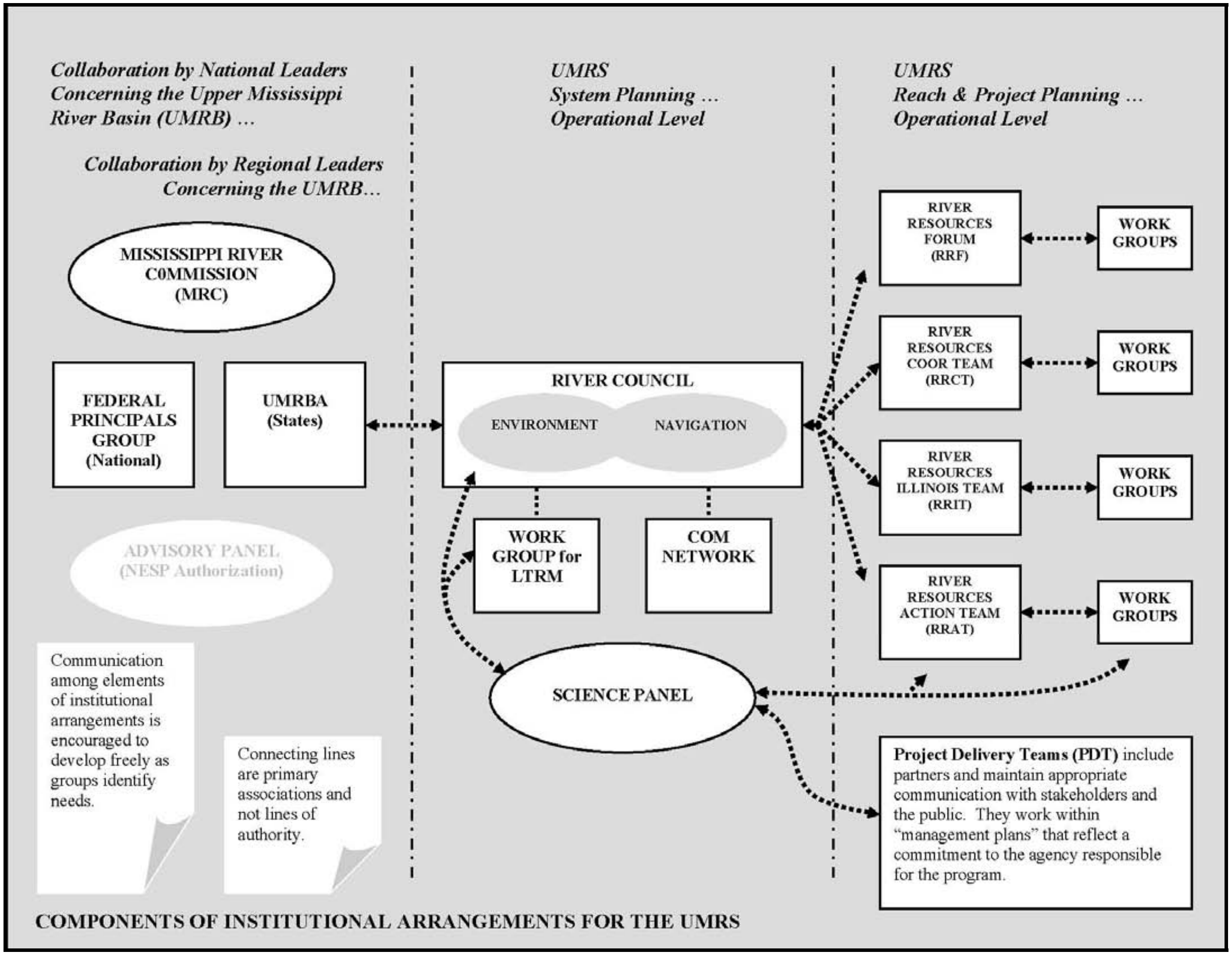

Figure 2. Proposed Upper Mississippi River institutional arrangements. The Science Panel is adjunct to and available to all partners.

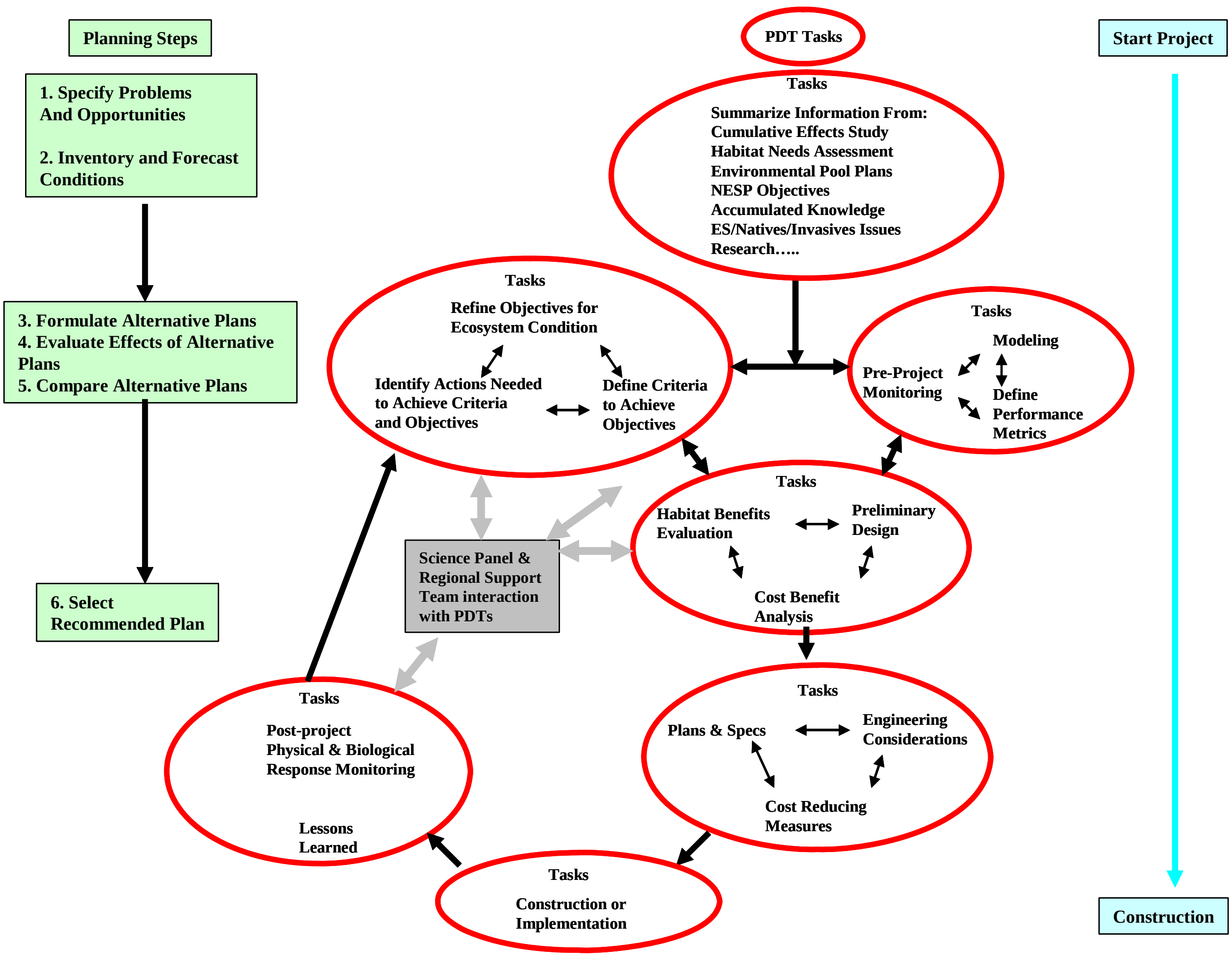

Figure 3. The Science Panel interacts with site and reach scale Project Delivery Teams at several steps in adaptive management process.

2 Goals and Objectives

A. Introduction

Repairing some of the ecological damage inflicted on our nation's aquatic resources is the foremost challenge for the emerging science of restoration ecology in the 21st century. It was only in the closing decade of the 1900s that the National Research Council (NRC 1992) defined ecological *restoration* (See Box 1) and its objective to emulate a naturalistic, self-regulating system that is integrated within its landscape. The term "restoration" is perceived differently by individuals and organizations due to the wide disparities in stakeholder interests, scientific knowledge, scales of interest, and system constraints encountered in practice (Wohl et al. 2005). Numerous revisions and synonyms for the term have appeared since the original NRC definition in 1992 that reflect a broader socio-cultural and watershed context for restoration practice in the 21st century (Box 1).

The Science Panel, based on consultation with NESP partner organizations, recommends adopting the Society for Ecological Restoration's (SER) definition (See Box 1) and the nine attributes they list as basis for determining when restoration has been accomplished, i.e. recovery (Box 2).

Box 1
Evolution of the term "Restoration"
(updated from National Research Council, 2004)

Restoration: returning an ecosystem to a close approximation of its condition prior to disturbance. (National Research Council 1992)

Rehabilitation: modifying selected sections of riverine systems to a predetermined structure and function (Gore and Shields, 1995)

Naturalization: shifting some characteristics of the regulated system closer to a natural pattern while maintaining or enhancing economic and social uses of the system (Rhodes and Herricks 1996, Sparks et al. 1998)

Normalization: the standard established from what is possible in a natural-cultural context as opposed to pristine conditions which are difficult, if not impossible, to define or achieve. (Stanford et al. 1996)

Restoration: returning a site to a condition similar to the one that existed before it was altered, along with its predisturbance functions and related physical, chemical, and biological characteristics. Goal is to establish a site that is self-regulating and integrated within its landscape, rather than to reestablish an aboriginal condition that can be impossible to define and/or restore. (Middleton 1999)

Restoration: the process of assisting the "recovery" of an ecosystem that has been degraded, damaged, or destroyed. (Society for Ecological Restoration 2002)

River restoration: assisting the establishment of improved hydrologic, geomorphic, and ecological processes in a degraded watershed system and replacing lost, damaged, or compromised elements of the natural system. (Wohl et al. 2005)

Box 2.
Attributes of Restored Ecosystems
(adapted from SER 2004)

A restored ecosystem:

1. contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure.
2. consists of indigenous species to the greatest practicable extent.
3. is represented by all functional groups necessary for its continued development and/or stability, or if not, they have the potential to colonize by natural means.
4. has a physical environment capable of sustaining reproducing populations of the species necessary for its continued stability or development along the desired trajectory.
5. functions normally for its ecological stage of development.
6. is suitably integrated into a larger ecological matrix or landscape with which it interacts through abiotic and biotic flows and exchanges.
7. has potential threats to its health and integrity from the surrounding landscape eliminated or reduced as much as possible.
8. is sufficiently resilient to endure the normal periodic stress events in the local environment that serve to maintain its integrity.
9. is self-sustaining to the same degree as its reference system and has the potential to persist indefinitely under existing environmental conditions, fluctuate in response to normal disturbance events, and evolve as environmental conditions change.

Successful river restoration re-establishes the pre-impact interactions among physical, chemical, and biological ecosystem components. Early river restoration efforts typically addressed restoring riverine ecosystem structure (e.g., pattern of habitats, riparian vegetation, and imperiled fishes). More recent programs are addressing restoration of river function (e.g., nutrient cycling) or dynamics (e.g., hydrologic regime). Because of the complexity of river ecosystems, restoring their structure, function, and dynamics presents fundamental challenges (Poudevigne et al. 2002), a top-down approach to UMRS restoration emphasizes objectives that apply at multiple spatial and temporal scales. In contrast, a bottom-up approach tends to address local site-specific objectives.

Specifying goals and objectives is frequently described as the most important task for restoration project planning, because it sets expectations for success, drives plans for action, and determines the kind and extent of pre-and post project monitoring (Ehrenfeld 2000). Agreeing on restoration goals and objectives is the first step in evaluating a range of possible restoration strategies (Hobbs and Norton 1996). Thus, setting goals and objectives provides a central element of effective river restoration and adaptive ecosystem management (figure 1).

Goals in the context of river management and restoration are often stated as broad societal values and desired future conditions (Harwell et al. 1999). They provide a “guiding image” (*sensu* Palmer et al. 2005) of a dynamic, ecologically healthy river that could exist within a regional context (Middleton 1999). This image for the UMR is influenced by twentieth century changes on the river’s hydrology, geomorphology, and biology from navigation, levee construction, channelization, human settlement, and connecting Lake Michigan to the Illinois River (UMRCC 2000). Goals should be based on a pre-project evaluation that assesses existing baseline conditions of the system being restored, factors leading to its degradation, and types of actions required to achieve targeted attributes (Middleton 1999, Hobbs and Harris 2001, Lake 2001). It is generally more realistic to agree on modest intermediate goals and reverse the decline of degrading sites than define overly optimistic ultimate goals and fail to achieve them. Ecosystem objectives for the UMRS are based in part on an assessment of historical, existing and forecasted future conditions (WEST 2000 and USACE 2000).

B. Goals and Objectives Team Members

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Support Team

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Paul West – The Nature Conservancy, Madison, Wisconsin

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C. Areas of Responsibility

One task of the Science Panel was to further refine, clarify and integrate the ecosystem goals and objectives provided by stakeholders and condensed by the UMR-IWW System Navigation Feasibility Study Science Panel (Lubinski and Barko 2003). Another task was to identify how ecosystem goals and objectives can be integrated into the adaptive ecosystem management process.

D. Ecosystem Objectives

Ecosystem objectives are central to river restoration and management. The UMRS ecosystem objectives will be adapted for use in planning, monitoring and evaluating restoration projects, not as strict guidelines. We anticipate and encourage further quantitative definition and refinement of the ecosystem objectives over time within the adaptive management framework.

E. Approach

Much effort has gone into establishing goals and objectives for the UMRS (e.g., Upper Mississippi River Summit 1996, UMRCC 1995, 2001, 2002, DeHaan et al. 2003, Lubinski and Barko 2003). We adopted the tiered approach recommended by Harwell et al. (1999) for ecosystem restoration and previously used by Lubinski and Barko (2003) for the UMR-IWW system. Arranging goals and objectives in a tiered approach emphasizes their hierarchical nature and the dependency of objectives on goals.

The 2003 Navigation Study Science Panel developed an adaptive management process to guide coordinated work for future integrated management efforts for the UMR-IWW (Lubinski and Barko 2003). As part of that effort, they compiled over 2,500 previous objectives for condition of the river system provided by stakeholders and synthesized them into 81 ecological objectives under five essential ecosystem characteristics: biogeochemistry (water quality), hydrology and hydraulics, geomorphology, habitat, and biota (Table 4 in Lubinski and Barko 2003). Essential ecosystem characteristics are ecological components considered critical to sustaining ecological systems and those aspects of ecosystems valued by stakeholders (Harwell et al. 1999). These objectives were refined and made more practical and quantitative, as recommended by the 2003 Navigation Study Science Panel, by reviewing each relative to a list of 20 questions and applied them to SMART criteria to them (Table 1; DeHaan et al. 2003, USFWS 2004). SMART criteria require objectives to be: Specific, Measurable, Achievable, Relevant, and Time-bound.

The ecosystem objectives were further refined by identifying the applicable spatial and temporal scales, linking them to management actions, action agencies, potential geographic ranges of application, performance indicators, monitoring activities and ecosystem services.

Table 1. Questions Used by Science Panel To Refine 81 UMRS Goals and Objectives
Relevant SMART criteria are in bold. See text for explanation of SMART criteria.

Question	**SMART Criteria**	**Response**
Is it an objective or an action?	**S**MART	If an action, revise wording to make it an objective, aggregate with other objectives, or delete
Can it be aggregated with other objectives?	**S**MART	Combine with other objectives, ID which
Can it be deleted from objectives?	**S**MART	Give reason why recommend deletion, (e.g., duplicative, aggregated, not achievable, etc.)
Can it be reworded to clarify?	**SMART**	Reword to clarify and SMART
Which UMRCC goal(s) does it address?	**S**MA**R**T	see UMRCC 9 Objs X 81 Nav Study Objs matrix
Can measurable indicators be developed?	S**MAR**T	Y or N
Can it be used in Report Card?	S**MAR**T	Y or N
Is it w/in NESP Authority?	SMART	Y or N
Who's responsibility to accomplish?	SMART	What agency should take the lead to accomplish
What spatial scale(s) does it apply to?	**S**MART	List spatial scales to which the objective applies: UMRS = S; Geomorphic Reach = R; Navigation Pool = P; Project Area = A; All.
What temporal scale(s) does it apply to?	SMAR**T**	List temporal scales (years) to which the objective applies: 1, 5, 10, 50, All
Is it technically achievable?	SM**A**RT	Y or N
Are boundaries identified within a sphere of influence?	**S**M**A**RT	Y or N
Does it apply to ecological structure, function, or both?	**S**MART	Structure (e.g., species or habitat composition, abundance, concentration, area, extent, etc.) = S, function (e.g., processes, growth, production, succession, interaction, rates, etc.) = F; Both = B
Does it address uncertainty?	SM**AR**T	Y or N
Does it incorporate variability?	SM**AR**T	Y or N
Does it incorporate sustainability?	SM**A**RT	Y or N
Is it amenable to non-structural approaches?	SM**A**RT	Y or N
Does it provide ecosystem goods & services	SMA**R**T	Y or N, what are they?
Are additional objectives required?	**S**MART	provide and give rational

F. Applicable Scales

Ecosystem objectives relate to one or more geographic scales of the river; system-wide, river reach, navigation pool, or project area. The objectives also have applicable temporal scales; some can be achieved sooner than others. Many of the ecosystem objectives are precursors to others, such as attaining objectives for water quality, geomorphology, and habitat that contribute to attaining objectives for biota. The spatial scales to which ecosystem objectives are applicable were identified from the UMR-IWW Feasibility Study Report (USACE 2004) as follows:

Basin. The Upper Mississippi River Basin is the entire watershed area of the Upper Mississippi River above the confluence with the Ohio River, excluding the Missouri River Basin (figure 4). The Upper Mississippi River Basin includes parts of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, South Dakota, and Wisconsin. The total area of the river basin is approximately 189,000 square miles.

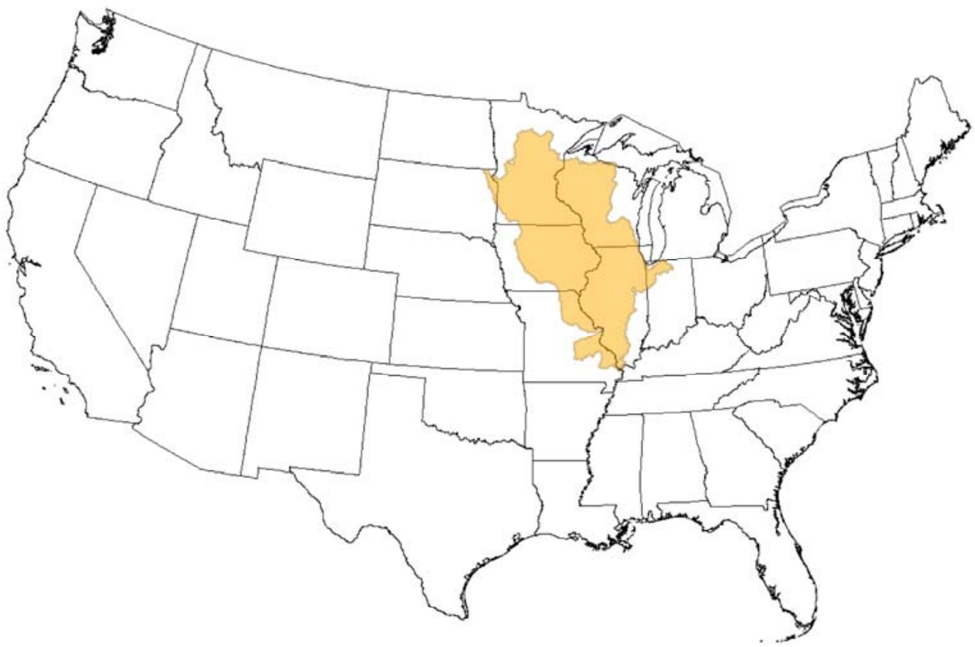

Figure 4. Upper Mississippi River Basin

System. The Upper Mississippi River System (UMRS) was as defined by Congress in the Water Resources Development Act of 1986 (WRDA 1986). The UMRS encompasses the entire channel and floodplain areas and the associated physical, chemical, and biological components of the Upper Mississippi and Illinois Rivers. The UMRS navigation system includes the commercially navigable reach of the Upper Mississippi River from Minneapolis, Minnesota, to Cairo, Illinois (854 river miles); the Illinois Waterway from Chicago to Grafton Illinois (327 river miles); and navigable portions of the Minnesota (15 river miles), St. Croix (24 river miles), Black (1 river mile) and Kaskaskia Rivers (36 river miles) (figure 5).

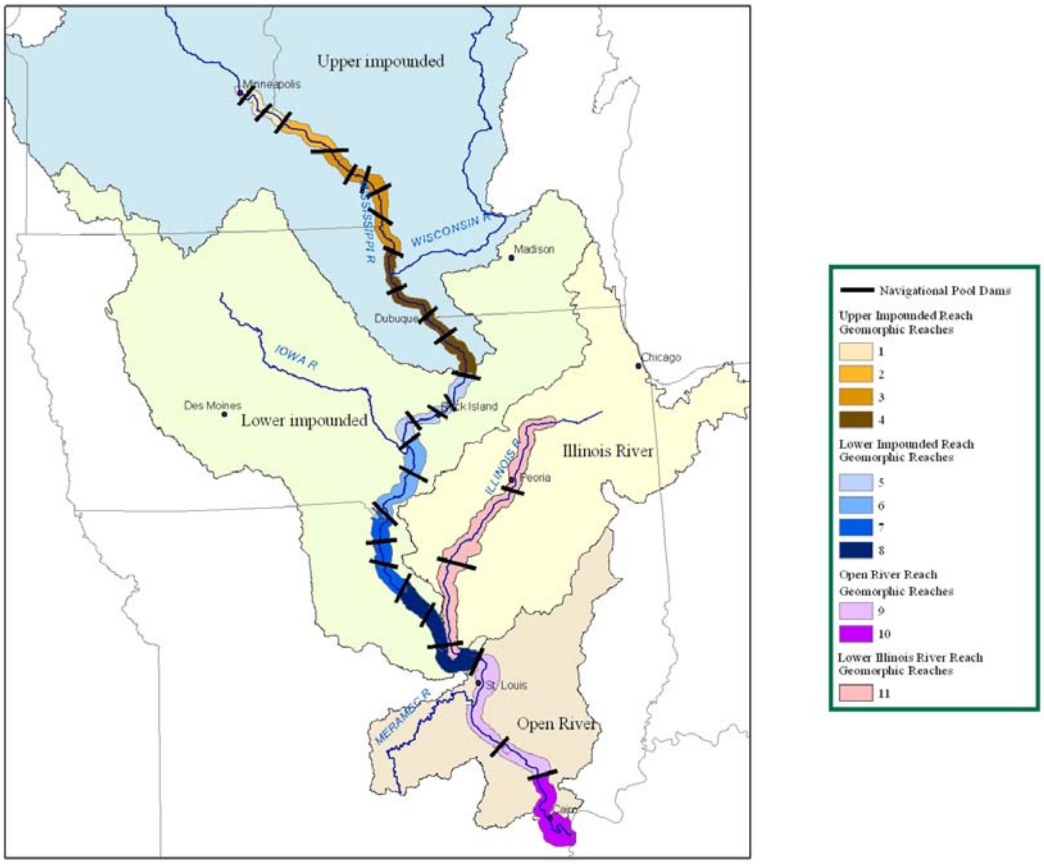

Figure 5. The Upper Mississippi River System is classified by four floodplain reaches and eleven geomorphic reaches. (WEST 2000)

Reach. A river reach is a continuous segment of river and its associated floodplain. In the UMRS, reaches are used to define portions of rivers at different scales (i.e., floodplain reach, pool reach, and reaches between two river bends or river mile points).

Commonly referenced UMRS Floodplain Reaches, defined largely by land use and habitat (USGS 1999), include:

- The **Upper Impounded Reach** includes UMRS Upper St. Anthony Falls Pool in Minneapolis downstream to Lock and Dam 13 near Clinton, Iowa.
- The **Lower Impounded Reach** includes UMRS Pools 14 through 27 near St. Louis, Missouri.
- The **Unimpounded Reach** is the unimpounded part of the UMRS beginning just south of the Missouri River (below Lock 27 near St. Louis) and extending to the mouth of the Ohio River at Cairo, Illinois.
- The **Illinois Waterway** extends from Chicago, Illinois to the confluence with the Mississippi River at Alton, Illinois.

The UMR-IWW can also be divided into 11 geomorphic reaches that reflect the river's adjustment to glacial events and other geological controls in the region (figure 6; WEST 2000).

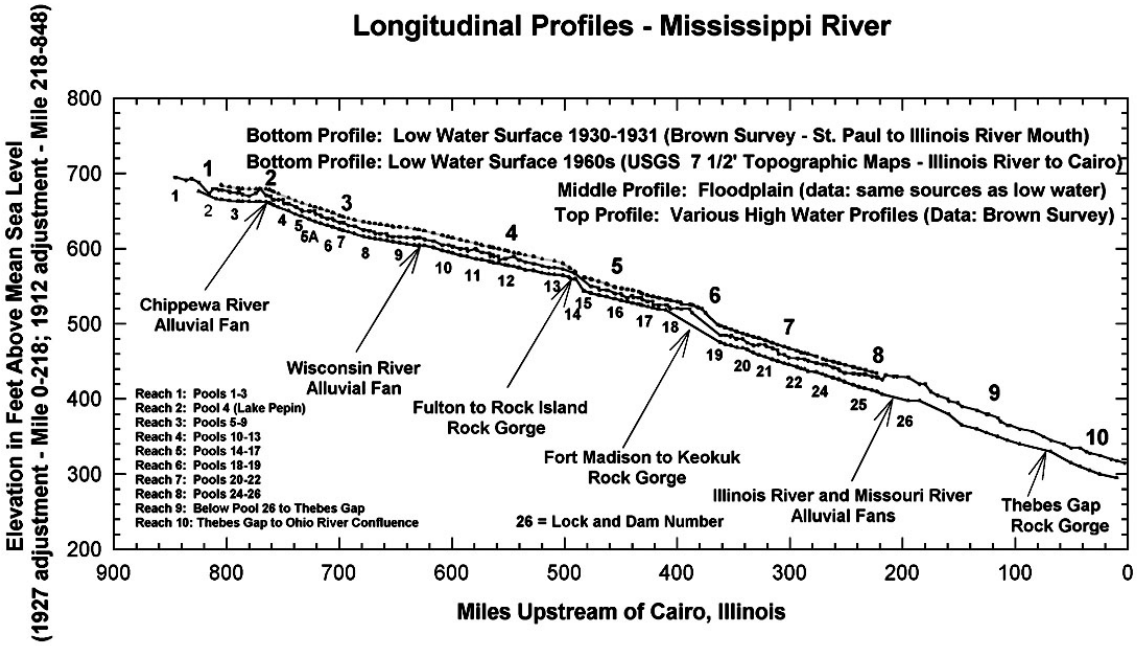

Figure 6. Upper Mississippi River Geomorphic Reaches (WEST 2000)

Navigation Pool. The area of water that is impounded and maintained at a higher level behind a navigation dam generally refers to the entire length of river between sequential dams. The pool scale extends to an entire navigation pool.

Habitat. The geomorphic and plant community characteristics of specific areas in the river, such as backwaters and channels or forests, grasslands, and wetlands (figure 7).

Project Area/Site. Projects are combinations of management actions affecting condition of the river ecosystem. They may incorporate several habitats within a defined geographic area frequently called a project site. The project, or site, scale is the area affected by the project. Project areas can range in size from several hectares to thousands of hectares. Individual projects may include a number of management actions.

G. Integration of Goals and Objectives in Adaptive Ecosystem Management

Goals and objectives for condition of the river ecosystem are central to river management (figure 8). Goals and objectives are logically linked to management actions, action agencies, indicators of ecosystem conditions, monitoring activities, and ecosystem services.

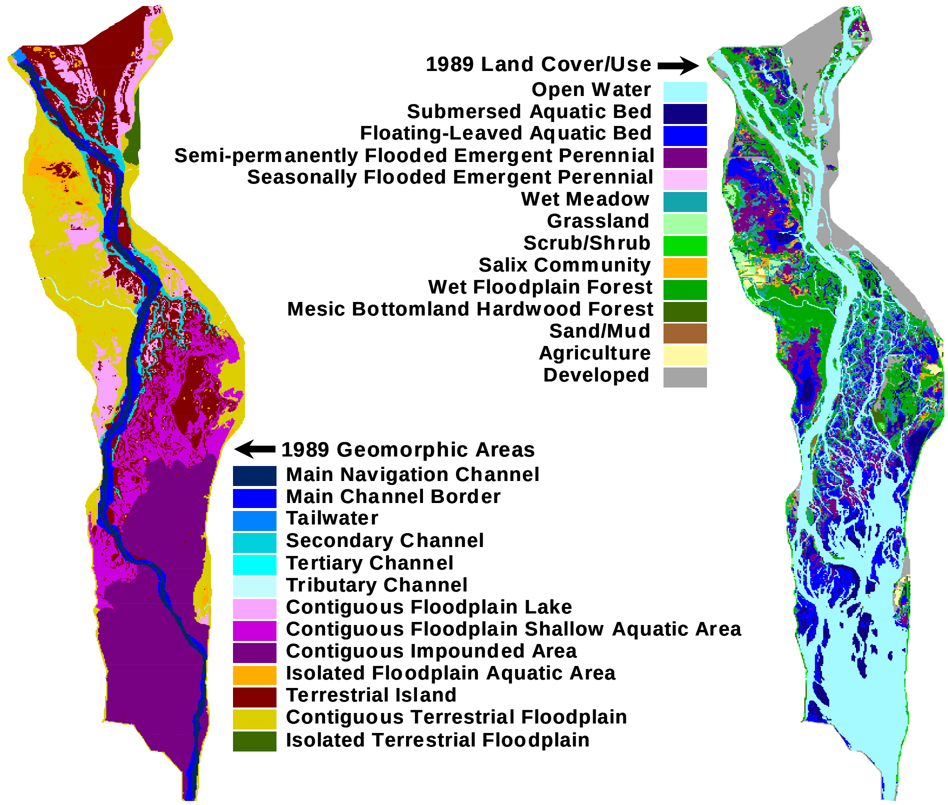

Figure 7. Upper Mississippi River Land Cover and Geomorphic Area Classifications (USGS 1999)

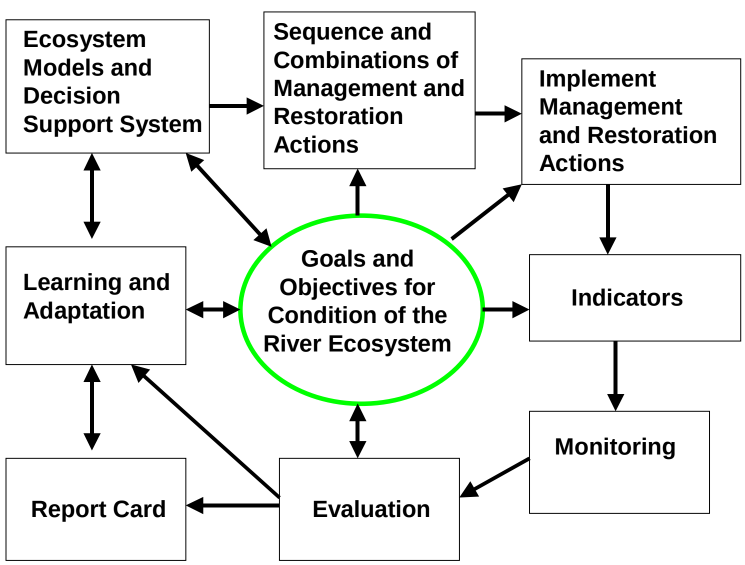

Figure 8. Relationships Among Goals and Objectives and Other Ecosystem Restoration Activities

1. Objectives and Management Actions. Management actions are activities intended to protect or change condition of the river ecosystem. There is a long, but finite list of potential management actions (DeHaan et al. 2003). Management actions range from small-scale frequent activities like daily changes to dam-gate settings to large-scale, once-in-a-lifetime, restoration projects. Each type of management action is implemented by one or more action agencies. Each ecosystem objective has a corresponding set of potential management actions taken to achieve it. Management actions each have a geographic range of historic, current, and potential application. Some actions are repeatedly implemented, such as dredging to maintain navigation or water level management to influence vegetation in moist soil management units.

2. Management Actions and Action Agencies. Action agencies are the units of social organization that implement management actions. Federal, state, and local agencies have legislatively authorized mandates and jurisdictions. Increasingly, non-governmental stakeholders including individual landowners, conservation organizations, and private industry also implement small and large management actions that affect the condition of the river ecosystem. Public-private conservation incentive programs have been quite successful in increasing upland and wetland habitat abundance.

3. Objectives, Performance Indicators and Monitoring Activities. Monitoring of projects should be focused on the project objectives. Each objective has performance indicators and associated monitoring activities. Performance indicators have specific parameters and appropriate units, frequency, duration, spatial resolution and time scales of measurement for monitoring. Project teams can identify the important ecosystem objectives, select the corresponding performance indicators, and identify practical monitoring activities. The results of monitoring are reviewed at the project scale during project evaluations. Multiple project evaluations, system monitoring, and focused hypothesis testing will be integrated at the river reach and system scales to enhance learning and program adaptations. See Chapter 4, *Report Card*, for selected indicators of socially valued and inherently important ecosystem components and services recommended for use in for condition of the UMRS ecosystem.

4. Objectives and Ecosystem Services. Chapter 3, *Economic Services*, discusses the value of adaptive management and restoration of the UMRS ecosystem to society. Each ecosystem objective, if attained, has a corresponding set of affected ecosystem services. Using a standard set of ecosystem services for the UMRS and through ecological modeling of the effects of management actions, we will be able to generate estimates of the benefits associated with attaining different ecosystem objectives. This should eventually prove useful in project planning, sequencing project implementation, and in reporting on program achievements.

H. Results

1. Ecosystem Goals and Objectives. Natural resource managers and other stakeholders were surveyed during the UMR-IWW System Navigation Feasibility Study to identify desired ecological conditions for the UMRS (DeHaan et al. 2003). More than 2,600 site-specific objectives were identified and captured in a GIS layer for the UMRS. System goals down to site objectives are organized in a hierarchy (figure 9). First tier goals address system-wide sustainability. Second tier goals are broad, qualitative, and emphasize biological structure and processes that contribute to ecological sustainability. The Navigation Study Science Panel condensed the initial set of over 2,600 ecosystem objectives into 81 objectives (Lubinski and Barko 2003). These objectives were further distilled by the Science Panel Goals and Objectives Team (table 2). The team refined, deleted, and combined objectives to make them more practical and quantitative.

Vision Statement

Upper Mississippi River Summit 1996)

"To seek long-term sustainability of the economic uses and ecological integrity of the Upper Mississippi River System."

First Tier Goals

(World Commission on environmental and Development 1987; adopted by Upper Mississippi River Summit 1996; endorsed by UMRBA and Joint governors' Proclamation 1997

"The balance of economic, environmental, and social conditions so as to meet the current and future needs of the Upper Mississippi River System without compromising the ability of future generations to meet their needs."

Second Tier Goals

(Grumbine 1984: *What is Ecosystem Management?; UMRCC 1995*)

1. Maintain viable populations of native species in situ
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

UMRS Ecosystem Objectives

(Lubinski and Barko 2003)

81 Ecological objectives and needs statements within five essential ecosystem characteristics: water quality, geomorphology, hydrology&hydraulics, habitat, and biota

Figure 9. Upper Mississippi River System Vision Statement and Tiered Goals and Objectives

Table 2. Upper Mississippi River System environmental objectives, recommended SMART criteria (Specific, Measurable, Attainable, Relevant, and Time-Bound), potential indicators, and models that can be used in predictive and alternative analysis. The indicators and models are referenced in later chapters.

Objective Number	Proposed UMRS Ecosystem Objectives	SMART Criteria	Indicators	Recommended Models
	1. Water Quality			
1.1	Reduce contaminant loadings to the river	Reduce [contaminant] loading rate to [mass range] per year from [source location (point or non-point)] by [year]	Contaminant loading rates	GHSSA (with Contaminants library),SWAT, ANNAGNPS, CASM, AQUATOX
1.2	Reduce contaminants in the rivers	Achieve [contaminant], [concentration range] in [water, sediment, plant tissue, animal tissue] in [location] by [year]	Contaminant concentrations	W2, ICM, SPARROW (USGS), CASM, AQUATOX
1.3	Reduce mobilization of sediment contaminants	Limit the mobilization of [contaminant] to less than [mass] from [location] during [time period]	Contaminant mass mobilization/dredging job	RECOVER, ADDAMS models
1.4	Achieve State Total Maximum Daily Loads (TMDLs)	Reduce [pollutant] loading rate to [mass] per day at [location] by [year]	Contaminant loading rates	W2, ICM, SWAT, FLUX, ANNAGNPS, CASM, AQUATOX
1.5	Reduce, maintain, or increase sediment loadings to the rivers	Reduce, maintain, or increase [wash load, bed load] sediment loading rate at [location] to [mass] per year by [year]	Sediment loading rates	GHSSA, other CHL Models, SIAM, CONCEPTS (ARS), CASM, AQUATOX, ICM, WASP, W-2
1.6	Reduce nutrient loading from tributaries to rivers	Reduce [N, P] loading rate to [mass] per year at [location] by [year]	N, P loading rates	GHSSA (with Nutrient's Library), W2, WETLAND MODELS, CASM, AQUATOX, ICM, WASP, ADH (with nutrient library)
1.7	Reduce nutrient export from the UMR to Gulf of Mexico	Reduce [N, P] export from the UMR to the LMR at Cairo IL to [mass] per year by [year]	N export rates	W2, ICM, WETLANDS MODELS, CASM, AQUATOX, WASP, HEC-RAS (with water quality)
1.8	Maintain adequate DO concentrations for fishes	Maintain at least 5 mg/l D.O. during [time] periods in [location] by [year]	DO concentrations	W2, ICM, USGS Screening Model, CASM, AQUATOX, WASP
1.9	Maintain water clarity sufficient to support submersed aquatic vegetation, aquatic invertebrates and fish species appropriate to location	Maintain [PAR, Secchi transparency, turbidity] of at least [lumens, depth, NTUs] during [percent of time, time of year] in [location] by [year]	PAR, Secchi transparency, turbidity	W2, ICM, Elly Best SAV model, USGS/Yin Model, CASM, AQUATOX, WASP

Table 2. Upper Mississippi River System environmental objectives, recommended SMART criteria (Specific, Measurable, Attainable, Relevant, and Time-Bound), potential indicators, and models that can be used in predictive and alternative analysis. The indicators and models are referenced in later chapters.

Objective Number	Proposed UMRS Ecosystem Objectives	SMART Criteria	Indicators	Recommended Models
	2. Geomorphology			
2.1	Enhance channel geomorphic diversity	Modify main channel border, secondary channel, or tertiary channel areas in [location], with [characteristics; e.g., depth diversity, slope, shoreline sinuosity, current velocity, substrate type, rate of change, number, or area] by [year]	Area, geometry, substrate type, current velocity in channel border areas	2D shallow water ADH (boundary conditions SIAM, HEC-RAS), Geomorphic/River Engineering Approaches, RMA-2V, FLO2DH, IIHR's 3D sediment transport model, or Delft3D Sed, Micro models
2.2	Modify the channels and floodplains of tributary rivers	Modify channels and floodplains of tributary rivers in [location], with [characteristics; e.g., tributary and distributary channel number, geometry, flow distribution between channels, floodplain elevation range, rate of change] by [year]	Number, area of tributary channels, geometry of channels and floodplains	2D shallow water ADH, possibly HEC-RAS, Geomorphic/River Engineering Approaches, RMA-2V,HIVEL, FLO2DH, IIHR's 3D sediment transport model, or Delft3D Sed, Micro models
2.3	Increase the extent and number of sand bars	Modify or create sand bars in [location], with [characteristics; e.g., area, slope, elevation, exposure time, substrate size, rate of change] by [year]	Number, area of sand bars	Probably multiple grain size 2D or 3D ADH, Geomorphic/River Engineering Approaches, IIHR's 3D sediment transport model, or Delft3D Sed, Micro models
2.4	Increase the extent and number of mud flats	Modify or create mud flats in [location], with [characteristics; e.g., area, slope, elevation, exposure time, substrate size, rate of change] by [year]	Number, area of mud flats	Geomorphic/River Engineering Approaches, IIHR's 3D sediment transport model, or Delft3D Sed
2.5	Increase the extent and number of gravel bars	Modify or create gravel bars in [location], with [characteristics; e.g., area, slope, elevation, exposure time, substrate size, rate of change] by [year]	Number, area of gravel bars	Geomorphic/River Engineering Approaches, RMA-2V, FLO2DH, HEC-RAS, HIVEL, ADH, IIHR's 3D sediment transport model, or Delft3D Sed
2.6	Increase the extent and number of islands	Modify or create islands in [location], with [characteristics; e.g., area, slope, elevation, plant community, rates of change] by [year]	Number, area of islands	Geomorphic/River Engineering Approaches, RMA-2V, FLO2DH, HEC-RAS, HIVEL, ADH, IIHR's 3D sediment transport model, or Delft3D Sed, Micro models

Table 2. Upper Mississippi River System environmental objectives, recommended SMART criteria (Specific, Measurable, Attainable, Relevant, and Time-Bound), potential indicators, and models that can be used in predictive and alternative analysis. The indicators and models are referenced in later chapters.

Objective Number	Proposed UMRS Ecosystem Objectives	SMART Criteria	Indicators	Recommended Models
	2. Geomorphology			
2.7	Increase the extent and number of rock and gravel riffles and substrate areas	Modify or create rock and gravel [riffles, substrate areas] in [location], with [characteristics; e.g., area, slope, substrate size, rates of change] by [year]	Number, area of rock and gravel riffles	Geomorphic/River Engineering Approaches, RMA-2V, FLO2DH, HEC-RAS, HIVEL, ADH, IIHR's 3D sediment transport model, or Delft3D Sed
2.8	Increase topographic diversity and elevation of floodplain areas	Modify topographic diversity [e.g., ridges and swales, elevational variability, rates of change] of floodplain areas in [location] by [year]	Number, area of modified floodplain areas	Geomorphic/River Engineering Approaches, IIHR's 3D sediment transport model, or Delft3D Sed
2.9	Modify delta areas	Modify delta areas in [location], with [characteristics; e.g., size, substrate composition, distributary complexity, rates of change] by [year]	Number, area of modified delta areas	Geomorphic/River Engineering Approaches, IIHR's 3D sediment transport model, or Delft3D Sed, Micro models
2.10	Modify exchange between channels and floodplain areas	Modify connectivity between the main channel and [location name and floodplain area type, e.g., contiguous backwater, oxbow, abandoned channel] floodplain area to [___] percent of river discharge at the [__] percent recurrence interval level of river discharge by [year]	Percent of river discharge flowing through backwater area	USGS River Habitat models, HEC-RAS, RMA-2V, FLO2DH, HIVEL, ADH, 2D depth-averaged models or fully 3D models. If biogeochemical fluxes are important then LES modeling would be useful, Micro models
2.11	Modify exchange between channels and floodplain areas floodplain areas	Modify connectivity between the main channel and [name] floodplain area to [___] percent of river discharge at the [__] percent recurrence interval] by [year]	Percent of river discharge flowing through floodplain areas	HEC-RAS, RMA-2V, FLO2DH, HIVEL, ADH, 2D depth-averaged models or fully 3D models. If biogeochemical fluxes are important then LES modeling would be useful
2.12	Modify contiguous backwater areas	Modify contiguous backwater areas in [location], with [characteristics; e.g. area, frequency of connection,] by [year]	Number, area of modified contiguous backwater areas	HEC-RAS, RMA-2V, FLO2DH, HIVEL, ADH, 2D depth-averaged models or fully 3D models. If biogeochemical fluxes are important then LES modeling would be useful, Micro models
2.13	Increase the number and extent of isolated floodplain lakes	Modify or create isolated floodplain lakes in [location], with [characteristics; e.g. size, depth diversity, shoreline complexity] by [year]	Number, area of geomorphic area types and floodplain features	HEC-RAS, RMA-2V, FLO2DH, HIVEL, ADH

Table 2. Upper Mississippi River System environmental objectives, recommended SMART criteria (Specific, Measurable, Attainable, Relevant, and Time-Bound), potential indicators, and models that can be used in predictive and alternative analysis. The indicators and models are referenced in later chapters.

Objective Number	Proposed UMRS Ecosystem Objectives	SMART Criteria	Indicators	Recommended Models
	3. Hydrology/River Hydraulics			
3.1	Naturalize hydrologic regime of main-channels	Re-establish [magnitude, timing, duration, frequency, rate of change] of main-channel annual flow regime to within the [range, e.g., 25th to 75th] percentiles of [dates; e.g., 1929 to1940] historical reference period hydrologic regime [value, e.g. 50%] percent of years in [location] by [year]	Discharge hydrograph	W2, IHA, HEC-RAS, RMA-2V, FLO2DH, HIVEL, ADH, or DHI's Mike11 or Delft Software
3.2	Reduce stage and discharge fluctuations caused by dam operation	Reduce the amplitude of water level fluctuations due to [name] dam operation to less than +/- [___] ft during the [date] to [date] time period by [year]	Stage hydrograph	W2, HEC-RAS, or DHI's Mike11 or Delft Software
3.3	Restore a more natural hydrologic regime in the navigation pools	Maintain water levels [___] feet [above or below} controlled pool elevation at Lock and Dam [__] to elevation [___] ft, during the [date] through [date] time period in [year] with fewer than [number] periods deviating from the target elevation.	Stage hydrograph	W2, HEC-RAS, RMA-2V, FLO2DH, HIVEL, ADH, or DHI's Mike11 or Delft Software
3.4	Restore a more natural hydrologic regime in floodplain waterbodies	Maintain water levels [___] feet [above or below} controlled pool elevation at Lock and Dam [__] to elevation [___] ft, during the [date] through [date] time period in [year] with fewer than [number] periods deviating from the target elevation.	Stage hydrograph	W2, ADH, HEC-RAS, RMA-2V, FLO2DH, HIVEL, ADH, or DHI's Mike11 or Delft Software
3.5	Naturalize hydrologic regime of tributaries	Re-establish [magnitude, timing, duration, frequency, rate of change] of tributary annual flow regime to within the [range, e.g., 25th to 75th] percentiles of [dates; e.g., 1929 to1940] historical reference period hydrologic regime [value, e.g. 50%] percent by [year]	Stage hydrograph	W2, ADH, HEC-RAS, RMA-2V, FLO2DH, HIVEL, ADH, or DHI's Mike11 or Delft Software
3.6	Increase storage and conveyance of flood water on the floodplain	Modify the storage and conveyance of [area] floodplain to [storage volume, roughness, conveyance] by [year]	Area of modified floodplain	HEC-RAS, RMA-2V, FLO2DH, HIVEL, ADH, or DHI's Mike11 or Delft Software
3.7	Reduce wind fetch in open water areas	Reduce wind fetch in [name] location to less than [___] meters by [year]	Wind fetch length	W2, USGS GIS model, HIVEL, ADH, GIS/Hand calculation

Table 2. Upper Mississippi River System environmental objectives, recommended SMART criteria (Specific, Measurable, Attainable, Relevant, and Time-Bound), potential indicators, and models that can be used in predictive and alternative analysis. The indicators and models are referenced in later chapters.

Objective Number	Proposed UMRS Ecosystem Objectives	SMART Criteria	Indicators	Recommended Models
	4. Habitat			
4.1	Provide desirable pattern of hydraulic conditions in tailwaters for fishes	Increase area in the [Lock and Dam No. __] tailwater with [conditions; e.g., current velocity] between [__ and __] m/sec by [year] and depth between [ ] and [ ] m by [year]	Current velocity	W2, NFS, ADH, RMA-2V, FLO2DH, HIVEL, U^2RANS, FLUENT, StarCD, CFX, Flow3D, Delft3d
4.2	Provide pathways for animal movements	Increase the number of [species] passing [lock and dam No., embankment, riprapped bank, levee] to [____ per year] by [year]	Number of [species] passing barrier	ADH, NFS, U^2RANS, FLUENT, StarCD, CFX, Flow3D, Delft3d
4.3	Modify the extent, patch size and successional variety of plant communities	[Increase] or [decrease] the [landscape structure attribute] of [land cover patch type] to [value range] in [location] by [year]	Landscape metrics	Forest Succession Models, Gap Models, ICM, GIS landscape model -USGS, SECASM, FORET, ZELIG
4.4	Modify the extent, abundance and diversity of submersed aquatic plants	[Increase] or [decrease] the [landscape structure attribute] of [submersed aquatic plant cover patch type] to [value range] with community diversity of at least [ ] [diversity index] in [location] by [year]	Landscape metrics	ICM, GIS landscape model-USGS, NavSAV, SECASM
4.5	Modify the extent, abundance and diversity of emergent aquatic plants	[Increase] or [decrease] the [landscape structure attribute] of [emergent aquatic plant cover patch type] to [value range] with community diversity of at least [ ] [diversity index] in [location] by [year]	Landscape metrics	ICM,GIS landscape model-USGS, SECASM
4.6	Restore and maintain large contiguous patches of plant communities	[Increase] the contiguous extent of [land cover patch type] to [value range] in [locations] by [year]	Landscape metrics	ICM
4.7	Modify backwaters to provide suitable habitat for fishes	Increase the [landscape structure attribute] of backwater [habitat patch type with conditions; e.g., depth, vegetation, D.O., temperature] to [value range] in [location] by [year] to benefit lentic fishes	Landscape metrics	NFS, W2, ADH, USGS/Soballe GIS Screening Model, NavFSH, U^2RANS,
4.8	Modify channels to provide suitable habitat for fishes	Increase the [landscape structure attribute] of channel [habitat patch type with conditions; e.g., depth, current velocity, substrate type] to [value range] in [location] by [year] to benefit lotic fishes	Landscape metrics	NFS, CEQUAL-W2, ADH, USGS GIS Screening Model, NavFSH, U^2RANS,

Table 2. Upper Mississippi River System environmental objectives, recommended SMART criteria (Specific, Measurable, Attainable, Relevant, and Time-Bound), potential indicators, and models that can be used in predictive and alternative analysis. The indicators and models are referenced in later chapters.

Objective Number	**Proposed UMRS Ecosystem Objectives**	**SMART Criteria**	**Indicators**	**Recommended Models**
4.9	Increase habitat corridor sizes and connectivity	Increase the corridor [length, width, connectivity] of [habitat patch type] to [value ranges] in [location] by [year]	Landscape metrics	DHI's Mike11 or Delft Software linked to appropriate GIS software
4.10	Increase vegetated riparian buffers along tributaries and ditches in the floodplain	[Increase] the [area, width, length, connectivity] of vegetated riparian buffers along tributaries and ditches to [value range] in [location] by [year]	Landscape metrics	GHSSA, SECASM
4.11	Increase woody debris in channels	[Increase] the volume of woody debris in channels in [location] to at least [volume/channel area] by [year]	Landscape metrics	
5.1	Maintain viable populations of native species throughout their range in the UMRS at levels of abundance in keeping with their biotic potential	Maintain populations of native [name; e.g., plant, macroinvertebrate, mussel, fish, amphibian…mammal] species of at least [___] [indicators of abundance] in [location] by [year]	Indicators of animal abundance	ICM, Index models USFWS/USGS, EDYS, NavLEM, NavMSL, Wisconsin fish bioenergetics models, CASM, 3D Hydrodynamics code + individual-based ecological model
5.2	Maintain the diversity and extent of native communities throughout their range in the UMRS	Maintain the diversity of the [name; e.g., plant, macroinvertebrate, mussel, fish, amphibian…mammal] community of at least [___] diversity index in [location] by [year]	Indicators of community diversity	ICM, Index models USFWS/USGS, EDYS, CASM, 3D Hydrodynamics code + individual-based ecological model
5.3	Reduce the adverse effects of invasive species on native biota	Reduce the adverse effects of [name invasive species] on [name native species or group] [growth, reproduction, mortality, geographic distribution] to [value range] by [year]	Indicators of plant and animal abundance	ICM, USGS invasion models, EDYS

2. Water Quality Objectives

Objectives grouped within the Water Quality Essential Ecosystem Characteristics were reduced from 12 to 9 objectives. Some were dropped or combined; several were moved to the Habitat EEC. The current list includes many objectives for contaminants and materials transported into, within, and out of the UMRS. The other water quality objectives define desired habitat conditions. Dissolved oxygen concentrations and water clarity are two important determinants of aquatic habitat for which clear objectives can be established.

3. Geomorphology Objectives

Geomorphology objectives were reduced from 25 to 13 by combining opposing and similar objectives. It is common in large complex systems like the UMRS to have an identical process be perceived as positive or negative depending on where they occur, so managers frequently identified opposing objectives (e.g., increase or decrease the extent of a geographic feature). The results of this review condensed the list of objectives and reworded them to identify many of the geomorphic features commonly referenced by UMRS managers. The SMART operational objectives can be used to identify the direction, magnitude, and rate of change for specific sites. Proper tracking of SMART criteria will ease evaluation and reporting.

The list of geomorphology objectives is based on the geomorphic areas commonly used to define river habitat. The lack of geomorphic processes among the list of objectives is not an oversight; the level of resolution required to define process-based objectives must be addressed as SMART criteria. Linkages among geomorphic objectives and the ecological stressors driving outcomes are included in the conceptual model for the UMRS (Lubinski and Barko 2003). The recommended decision support system can guide project teams through a planning process that integrates these relationships.

4. Hydrology and Hydraulics Objectives

Two of the original hydrology and hydraulics objectives were moved to the Habitat EEC. Hydrology objectives have been, and continue to be, focused on more natural seasonal river stages that are believed to support a diverse and productive ecosystem. The degree to which large-scale manipulations (e.g., drawdowns) can be undertaken, and the effectiveness of such manipulations, is becoming better understood. There is also an uneasy realization that, for some objectives in some river reaches, more extraordinary measures may need to be taken. In areas where ambient water quality and hydrologic conditions prohibit aquatic plant production, it may be necessary to isolate and manage wetland units independent from the river during parts of the year.

Hydraulic objectives can be better defined as important bathymetric data are obtained. With detailed bathymetry and available hydrologic data, modelers are able to estimate hydraulic conditions over large areas (e.g., entire navigation pools or river reaches) with high resolution. Project planners, working in sub-areas representing distinct hydrologic units, can define fine-scale flow distribution objectives that are typically achieved by building or modifying channel training structures and dredging. These objectives are established to enable scouring flows to maintain channels, provide improved water quality conditions through modifying hydraulic exchange rates, and maintain suitable water levels to encourage plant growth.

5. Habitat Objectives

Habitat objectives were reduced from 17 to 11 by consolidating similar objectives. The list of objectives is a mix of changes in abundance and diversity of habitat in general and specific habitat classes or animal habitat. Pathways, connectivity, and patch size are some of the landscape scale objectives. These objectives are very broad; the SMART objectives need to be used at a site scale to be quantitative.

6. Biota Objectives

Objectives for biota were condensed the most; 17 objectives were condensed into three. The prior list itemized objectives to maintain viable populations and the diversity and extent of native species for each major class of animal and plant in the UMRS. The refinement now generalizes the objectives to maintenance of viable populations distributed across their native range. Species objectives are addressed as SMART objectives. Invasive and exotic species introductions are also of great concern throughout all ecological communities.

I. Integrating Goals and Objectives

As stated above, goals and objectives for condition of the river ecosystem are central to river management. Goals and objectives are logically linked to management actions, action agencies, indicators of ecosystem conditions, monitoring activities, and ecosystem services. We compiled a set of matrices that make these linkages and can serve as a framework for spatially referenced program planning and decision support system (Appendix A). The matrices are well-developed but are not complete. Not all are included in the Appendix. The information in the matrices needs to be reviewed and updated regularly.

J. Discussion

The development of this set of 45 objectives provided clarity to the language in the previous set of objectives, but more importantly, it refined the structure in which the process of setting system-wide to site scale objectives can be conducted. Work on the prior set of objectives stopped when 2,600 objectives had been categorized and combined into 81 general objectives. The current effort was to make those objectives useful to river managers and planners. The structure developed provides a general set of objectives for Water Quality, Geomorphology, Hydrology, Habitat, and Biota. Project Delivery Teams working at pool and site scales must develop the SMART (i.e., specific, measurable, achievable, relevant, and time-bound) criteria for relevant objectives that result in actions or projects. The objectives categorized by Essential Ecosystem Characteristics provide a top-down structure for PDTs to work within. The essential ecosystem characteristics and Conceptual Model guide them to consider important ecosystem structures and processes, the objectives get them to think about common ecosystem features or processes that may be considered at a site. The planning process is also a bottom-up exercise. As many PDTs begin work and address new resource issues or develop innovative restoration approaches, they will feed back into the objectives from the site scale. They will also be populating a large set of SMART objectives that will develop over time. Occasional reviews of the entire set of objectives will assure the Science Panel and program managers can consolidate both approaches and communicate improvements to all stakeholders. Providing a planning template in the form of a decision support system will also help manage the information developed through site and reach planning.

This review of objectives helped identify the scales at which planners can work in concept and where they can become quite quantitative in their design criteria. The split is roughly at the pool scale. Discrete hydrologic units, or habitat complexes, within pools formed around an island or set of islands, a large lake, tributary deltas, etc. seem to be the scale where people can start to see the fine habitat details and imagine how changes could be affected by management or restoration. Detailed land cover models have been available at the pool scale for about 15 years, so it is a view that planners are familiar with. As bathymetry data are collected and numerical hydraulic flow models are developed, the detail at which aquatic habitat can be defined is greatly refined and flow through individual channels or around specific structures within hydrologic units is relevant. High-resolution LIDAR floodplain topographic data would allow similar resolution in floodplain terrestrial areas, especially if a high-fidelity vegetation successional model is developed. These high-resolution planning tools allow the development of refined objectives that can be incorporated into the decision support system to help estimate and report program outcome High resolution site objectives may be additive in terms of achieving larger reach objectives, such as 100 acres of wetland at a site adding to a 1,000 acre wetland objective for the pool, or a 10,000 acre objective for the system. An objective to have 200 cubic feet of water passing through an overflow channel in a restored island complex at 3 feet/second during April, however, is not necessarily additive. That detail may result in some number of acres of fish habitat, or it may even impose poor habitat conditions for a short period to achieve the desired scour in the channel that creates more optimal habitat the remainder of the year. The physical process objectives at a project site can be stated and illustrated with model results quite clearly to communicate design criteria and expected outcomes among biologists, engineers, planners, and the public, but the detail may not be relevant at larger scales. It must be emphasized that this level of detail takes significant time and energy that is viewed by some as detracting from the actual restoration activities.

Another important finding of this review was that at large scales, every project is an “ecosystem” project. Planning at large scales incorporates habitats, features, processes, etc. that affect many groups or species of plants or animals. It is only at the site scale, which may be 1,000s of acres or even a whole pool, that habitat benefits of project features, like acres of deep water created by dredging, configuration of islands and borrow areas, planting mixes, etc., can be considered. Those are the details that allow more resolved benefit calculations using tools like the USFWS Habitat Evaluation Procedures or process-based ecosystem models.

1. Future Role of the Science Panel in Goals and Objectives

Objective setting is not a static process. We expect objectives to change in an adaptive fashion as their implementation and monitoring increases knowledge and scientific understanding. As this progress report was being written Tear et al. (2005) published a paper advancing five fundamental principles for setting conservation objectives. Their purpose was to help conservation practitioners answer the question, *how much is enough?* for imperiled species recovery and conserving or restoring ecosystem integrity. These principles are: (1) state clear goals; (2) define measurable objectives; (3) separate science from feasibility; (4) follow the scientific method, and; (5) anticipate change. They provided further guidance through a set of more prescriptive science-based standards to maximize the probability of success. These standards are: (1) use the best available science; (2) provide multiple alternatives; (3) set objectives for both short and long time periods; (4) incorporate the “three Rs”: representation, redundancy, and resilience; (5) tailor objectives to the biological system of concern, and; (6) evaluate errors and uncertainties. Progress toward defining ecosystem objectives for the UMRS is progressing in the right direction relative to these guidelines. However, areas for improvement remain. UMRS stakeholders should continue to refine objectives and implement management and restoration actions relative to these principles and standards.

2. Decision Support System. We recommend that a decision support system for UMRS ecosystem management and restoration be developed that enables application of a family of ecosystem models to evaluate the potential ecological and cost effectiveness of combinations of management and restoration actions to achieve ecosystem objectives. A decision support system should also be a means of tracking progress, in the sense of keeping records of restoration projects, including project objectives, management and restoration measures applied, areas affected, project information, performance indicators, monitoring activities, monitoring results, ecosystem services affected, and lessons learned (figure 10). The decision support system will be used by all project teams to assist their planning process.

The Ecosystem Objectives Matrix (Appendix A) provides an initial framework for a decision support system. The matrix documents the relationships among ecosystem goals, ecosystem objectives, project types, project objectives, applicable scales, management and restoration actions, action agencies, areas affected, project information, performance indicators, and ecosystem services.

We recommend that a decision support system be developed using the ecosystem objectives matrix and the family of ecosystem models to assist project sequencing, planning, monitoring, evaluation, reporting on restoration progress and on condition of the river ecosystem. The decision support system would be a GIS database to enable visualization and analysis of the spatial arrangement of ecosystem conditions, projects and management measures. The GIS-based decision support system would enable spatially explicit application of ecosystem models (or their compiled results) in project planning.

The decision support system would incorporate incremental analysis techniques to identify the best value sequence of management measures to apply within project areas to attain objectives for condition of the ecosystem and to increase ecosystem services. This system would be made available to project teams, resource managers, and decision-makers via a NESP Internet site to include information about the program; ongoing projects; a synthesis of ecosystem modeling results; instructions for use of the decision support system; and the Ecosystem Restoration and Management Plan currently being developed. The site would enable tracking implementation of management and restoration measures and system response as revealed by monitoring.

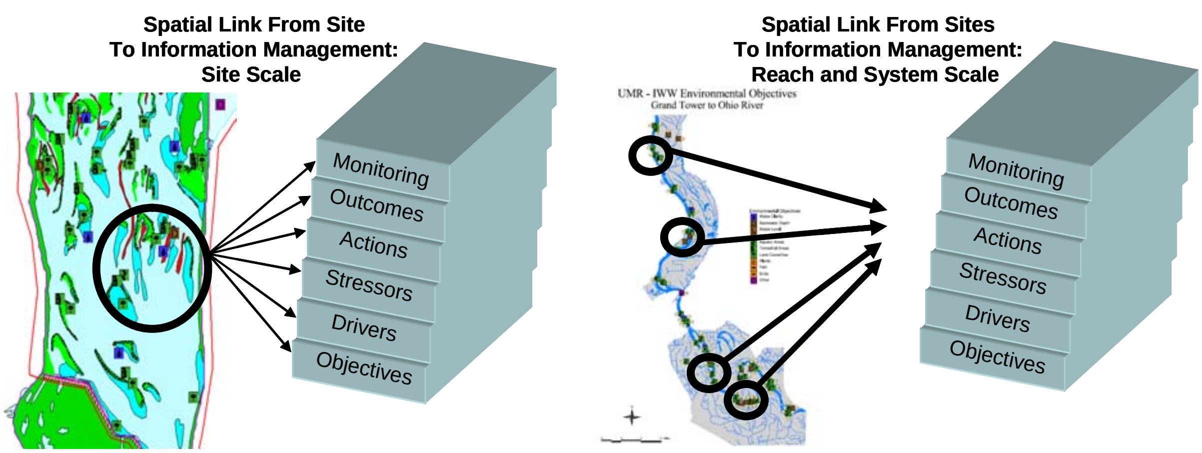

Figure 10. An Upper Mississippi River System Decision Support System is proposed as a valuable planning and management tool to track objectives, action, and outcomes at sites to make project or management assessments, or at large scales to make reach and system assessments.

3 Ecosystem Services

Rivers have provided free ecosystem services to humans for thousands of years. Their ability to provide food, water, and transportation has been vital to the development of many civilizations. Unfortunately, civilizations have often found out how valuable ecosystem services are when the service has been lost or degraded to the point where the sustainability of the socio-economic system is threatened. Then, the value of the service has been reflected in the cost of the artificial structures that have to be built, substitute or imported resources, ecosystem restoration measures needed to replace the lost service.

Modern humans are increasingly realizing that river ecosystem quality, regional economic prosperity, and cultural well-being are all part of the same place-based equation. Not only do each of these three components factor into regional socio-economic sustainability, but also each is dependent at some level on the others. Through the exploration and evaluation of ecosystem services, we can begin to understand what levels of use a river can withstand before it starts exhibiting unacceptable levels of ecosystem health. Further, greater understanding of ecosystem services will foster more responsible valuations of the benefits that people derive from them.

Relative to UMRS, several different audiences are likely to use information about ecosystem services. Congress and the Corps will seek this information to answer questions about ecosystem management and restoration costs and benefits. The general public will use this information to evaluate the condition of the river resource by the services it does or does not provide. The recreational community and municipalities will use the information to regularly reaffirm and broaden their support of restoration projects. Conservationists will use this information to design strategies for implementing payment or trading programs that equitably support the maintenance of quality natural resources (Douglas 2001). For example, The Nature Conservancy is working with government agencies in Brazil to direct water fees that originate from land use protection programs to restore upstream forests (Rosa and Kandel 2002). Also, nutrient farming on the Illinois River, with subsequent conservation benefits, is being investigated by the city of Chicago as a less expensive means to meet its waste treatment requirements.

A. Area of Responsibility

The Ecosystem Services Team was established to insure that the river managers comprehensively addressed the concept that the Upper Mississippi River ecosystem provides a variety of benefits to humans, and that reductions in any of these benefits attributable to a given river use need to be understood and factored into future river management decisions. The study of ecosystem services is relatively young. Methods and assumptions for quantifying river ecosystem services are far from being standardized. The first area of responsibility for the Ecosystem Services Team, therefore, was to describe the concepts of ecosystem services, and to develop recommendations related to incorporating ecosystem services into the adaptive management process. Initially, this required:

- review of ecosystem services literature and engagement of experts in this field,
- identification of ecosystem services provided by the UMRS

- identification of practical and acceptable methods for quantifying ecosystem services
- identification of practical and acceptable methods for assigning value to ecosystem services
- recommendations on incorporating consideration of ecosystem services in management decisions.

B. Members

Science Panel

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Support Team

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C. Approach

The approach of the Ecosystem Services Team in FY 05 was to review pertinent reports and publications on ecosystem services in general, and more specifically the services provided by rivers, and to bring important concepts (i.e., definitions, assumptions, and issues) to the attention of the Science Panel at meetings and via electronic communications.

Because of the great interest but lack of standardized, or consensus-based, approaches surrounding ecosystem services and their quantification, the Science Panel will need to quickly present ideas to Corps program managers, river managers, and stakeholders. The process of evaluating and quantifying UMR ecosystem services will require wide-spread consensus. The consensus-building will be most effective if it starts soon.

Additionally, the approach to exploring ecosystem services has included the tracking of several projects that have potential demonstration value. These include the functional assessment work going on at the Emiquon site along the Illinois River, and The Nature Conservancy biodiversity assessment programs being initiated on the Upper Yangtze River and the lower Mississippi River. Significant other large scale projects that should also be considered in the review include restoration planning for the: Columbia River, Cal-FED, Colorado River, Kissimmee River, Chesapeake Bay, Coastal Louisiana, and the Everglades.

D. Integration Plan

Our thinking and actions related to ecosystem services need to be integrated with several other areas of Science Panel work. Eventually, we anticipate that the process for quantifying several river ecosystem services will become understood and accepted enough so that goals and objectives for each such service can be associated or formulated. We also anticipate that one or more ecosystem services provided by the UMR will be proposed as key indicators, and therefore measured and monitored as part of the report card process. We anticipate that ecosystem services will be quantified and used to estimate benefits in restoration project planning and in tracking program accomplishments. As a result, staff working on the UMR goals and objectives and the report card process need to be continually updated on progress being made by the ecosystem services team.

Progress on ecosystem services is very likely to reveal some major gaps in what we know about the extent, quality, and sensitivity of the services being studied, as well as if and how much those services have degraded over time. Part of the adaptive management process includes the establishment of learning objectives. Future learning objectives must be directly linked to questions raised during the process of exploring ecosystem services.

Perhaps most importantly, we anticipate that quantifying ecosystem services will provide a never before available tool for setting priorities for the different kinds of management actions being considered under the auspices of NESP. The process we develop for quantifying ecosystem services will be designed to answer questions about which management actions yield the most cost-effective and vital ecosystem outcomes. Optimization analyses will be designed to show maximum benefits across all relevant ecosystem components, while at the same time providing the minimum required conditions necessary for each individual component.

E. Results

1. Definition

Because of the many problems that might spring from developing a UMR-specific set of terms for discussing ecosystem services, we propose terms and definitions that are well established in the scientific literature. Therefore, we recommend the following definition of "ecosystem services":

Ecosystem services are the benefits people obtain from ecosystems

(Source: U. N. Millennium Assessment Report 2005).

We also recommend using the Millennium Assessment Report's categorization scheme for the different kinds of ecosystem services:

Provisioning Services: These services generate products. Examples include: food, water, timber, and fiber.

Regulating Services: These services are associated with the regulation of ecosystem processes. Examples include air, water (quantity and quality) and climate regulation.

Cultural Services: These ecosystem services create non-material benefits valued by people. Examples include: spiritual enrichment, cognitive development, reflection, and recreational enjoyment, and aesthetic appreciation.

Supporting Services: These services are necessary for the production of the other services. Their impacts on humans are often indirect and they may influence the other services over long periods of time. Examples include soil formation, photosynthesis, and primary production.

2. Identification of Ecosystem Services Provided by Rivers

The following examples of ecosystem services illustrate some of the benefits that people receive from large rivers. Annotations elaborate facts known about the Upper Mississippi River and its basin. The list of services was modified from the list developed the U.N. Millennium Ecosystem Assessment (2005). Transportation was added as an additional service under the "cultural services" category.

Provisioning Services

- *Food* [1] – Approximately 1.3 million acres of UMRS floodplain are used to produce crops. Historically, the floodplain-river ecosystem supported a large commercial fishery. Approximately 2/3 of the UMR basin is used of agricultural production (79 million acres), producing corn, soy, dairy, and meat products.
- *Fiber* – Approximately 1/3 of the basin is in forest cover (40 million acres). The majority of these acres are used to produce timber. Timber is locally harvested in the floodplain.
- *Genetic resources*
- *Biochemicals, natural medicines, pharmaceuticals*
- *Fresh water*[1] – The UMR supplies drinking water for 30 million people in the basin. Numerous water withdrawals support industrial use, power generation, and irrigation.
- Biodiversity – The UMR is a stronghold of Midwestern terrestrial and aquatic species.

Regulating Services

- *Air quality regulation* – forests and croplands produce oxygen and sequester carbon.
- *Climate regulation*
- *Water regulation* [1] – Wetlands of the UMR floodplain and basin regulate the timing and magnitude of flooding by slowing the velocity and locally storing water.
- *Erosion regulation* – Northern forests maintain relatively high water quality, floodplain vegetation traps sediment and protects against bank erosion.
- *Water purification and waste treatment* [1]– The UMR floodplain and wetlands in the basin filter sediments, nutrients, and chemicals from the water.
- *Disease regulation* -
- *Pest regulation* -
- *Pollination* -
- *Natural hazard regulation* – This service generally refers to coastal areas. Flood regulation is covered above.

Cultural Services

- *Spiritual and religious values*
- *Aesthetic values* – Significance of the aesthetic value is recognized through designation of the Federal and state parks, monuments, historic sites, and a scenic riverway.
- *Recreation and ecotourism* [1] – $6.6 billion is annually generated from over 12 million visitor-days.
- *Transportation* [1] – The UMR system is used to ship large quantities of grain, coal, and other bulk cargo. In 1999, 151 million tons of commodities were shipped on the UMRS and lower MO rivers. Nearly 60% of the tonnage was grain and coal.

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[1] services that large floodplain-river ecosystems provide in substantial quantity

Supporting Services (these services influence the supply of provisioning, regulating, and cultural services)

- Soil formation
- Photosynthesis
- Primary production
- Nutrient cycling
- Water cycling

F. Discussion

Ecosystem services are elements of a relatively new discipline, in spite of the wealth of literature that already surrounds the topic. Few services have been quantified at the scale of the UMR basin. Most of the exercises to date have been academically-oriented, not driven by specific, real-world management programs. As a result, few quantification methods have been generally accepted as standards.

The Science Panel, the Corps, and UMRS stakeholders need to collectively consider how additional information about ecosystems services is going to be incorporated into the adaptive management of the UMR. Many important questions need at least tentative but broadly supported answers before additional progress can be made. Who will be trusted to quantify specific UMR ecosystem services? If a specific ecosystem service (e.g., the ability of a connected floodplain reach to reduce flood peaks, for example) can be quantified to the satisfaction of the stakeholders, how will this information be used to either steer future river management and restoration activities, or to make other river management decisions? The Ecosystem Services Team has identified the following issues that will need to be addressed in the early phases of the NESP to help answer the above questions and effectively build management consensus and buy-in to the ecosystem services concept. Embedding ecosystem services into UMRS ecosystem management and restoration therefore, will take time and a thorough understanding by river managers of assumptions and processes involved with their quantification.

1. Prioritization of the Ecosystem Services Requiring Initial Attention

For this report, the Science Panel instructed the Ecosystem Services Team not to make any attempt to prioritize the ecosystem services provided by the UMR. This guidance was based on the belief that many people don’t understand what ecosystem services are, how many services a river ecosystem provides, or the possible economic magnitude of a service provided by the UMR. The Science Panel recommended that the first necessary communication step is simply to focus on clarifying the ecosystem services that the UMR provides.

However, it is unrealistic to think that all of the ecosystem services provided by the UMR have the same value to human society, or that they can be quantified at the same time. UMRS stakeholder input on the services of greatest interest is needed.

2. Frames of Reference

One challenge among many, to quantifying an ecosystem service is to determine the frame of reference that will be used to conduct the valuation. Scientists have suggested that different values of a service are likely to result from an analysis if the overall goals of the process are to be efficient, fair, or to create a sustainable system. The most common valuation process in the past, an efficiency process, has included methods whereby the “willingness to pay” for a service is determined. The valuation of the same service, if approached from a fairness or sustainability frame of reference, is likely to be much higher than if calculated by a “willingness to pay” method. Therefore, it is clear that river managers who will be using future ecosystem service valuations need to have a deep and common understanding of the frame of reference used to bind the analysis.

3. Common Currency

The impact of floodplain restoration, as an example, can be quantified in terms of volume of water (if the objective of the project is flood regulation), concentration of nutrients (if the objective of the project is water quality), or the abundance of waterfowl (if the objective is an increase in hunting-days). If restoration projects are to be compared in terms of the ecosystem services they provide, some discussion of either developing a common currency or an acceptable “equivalents” system is necessary.

4. Scaling Services from Project Site to Reach to System

What is the most effective and relevant spatial scale for quantifying a specific ecosystem service? Can or should the services provided by selected sites within a reach be added to estimate the value of the service at a larger scale? It is important to acknowledge the temporal and spatial variability in the quantity of services provided, but at the same time, generally applicable guidance is required so that, for example, valuations of the Unimpounded Reach of the UMR, are comparable to valuations made for the Impounded Reaches.

G. Future Role of Science Panel in Ecosystem Services

The Science Panel needs to identify and make contact with international experts in the field of quantifying river ecosystem services and bring expertise to bear on the UMR adaptive management process. The Science Panel needs to foster discussion about the important ecosystem services and approaches for quantifying and assigning value to them with UMRS stakeholders.

The Science Panel needs to work with the Corps and UMRS stakeholders to establish an effective series of communications designed to present conceptual and technical issues to decision makers so that the eventual valuations of ecosystem services fully function as intended by the river management community.

4 Report Card

A. Area of Responsibility

The Report Card Team developed a process for reporting the status of a set of ecosystem indicators for tracking and communicating progress toward achieving UMRS ecosystem goals and objectives. The Report Card concept was explored and recommended by the UMR-IWW System Navigation Feasibility Study Environmental Science Panel (Lubinski and Barko 2003) and included in the Feasibility Study recommended plan.

B. Members

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Jean O'Neil – USACE (Retired), ERDC, Waterways Experiment Station, Vicksburg, Mississippi.
Michael Reiter – Delaware State University, Dover, Delaware

C. Approach

The Report Card Team was formed to draft a framework for communicating the condition of the UMRS Ecosystem. The Team had several examples from other ecosystems and the recommendations from the Navigation Study Environmental Science Panel. The Team solicited input and advice from several other teams to facilitate the communication requirements of the adaptive management cycle.

The Report Card Team invited specialists from outside the UMRS to discuss approaches used in other systems. An introductory conference call was followed by a workshop in Davenport, Iowa, in June, 2005. Drs. Mark Harwell and Michael Reiter provided their experience with reporting to diverse stakeholders in the Everglades and Chesapeake Bay. Both projects are excellent examples of large project coordination efforts—the Everglades work offered more on policy and communication; the Chesapeake Bay work offered more on modeling and evaluation. Dr. Jean O'Neil helped the Team embrace the concept of conceptual modeling in the context of report card development.

A Report Card Workshop was held in September, 2005. During the workshop, the Team was briefed on the objectives and status of other teams, and coordination was initiated in the development of ecological indicators. Issues of scale, timing, and measurement were found to be common to most indicators.

D. Integration Plan

An ecosystem report card is a tool used to communicate complex information to a diverse audience and to integrate status of ecosystem condition and processes with ecosystem objectives, management actions, and services. It needs to be scalable and reflect the ecosystem conceptual model for the UMRS.

With consensus developing on ecosystem objectives and attendant indicators, the Report Card Team can begin to refine the indicator list to scale-appropriate parameters that represent ecosystem conditions at reach and system scales. Indicators that can synthesize information across ecosystem components will be selected. The Monitoring Team recommendations for reach and system-scale monitoring will strongly influence indicator selection. The Monitoring Team will assure the technical integrity of indicator measurements and analysis. The monitoring and modeling team will coordinate to synthesize data into useful ecosystem scale results for reporting. Reporting parameters may change as we learn more about our ability to understand, measure, and value specific ecosystem services.

E. Results

The Navigation Study Science Panel recommended the use of a system-wide Report Card for the condition of the UMRS ecosystem. They also developed a set of criteria for indicator selection and stepped through a set of indicators (table 3) to demonstrate how the criteria could be applied (Lubinski and Barko 2003). The criteria synthesized from guidance from prior studies were: policy and management relevance, technical merit, and practicality.

The work of Harwell et al. (1999) was also influential during the first Science Panel and remains so. The understanding that reporting requirements differ along a continuum of technical understanding and ecological scales is very important for many aspects of adaptive management. Technical managers and site planners may require monitoring many parameters at fine resolution to understand ecosystem responses to management actions and restoration. Program planners, however, may be more interested in regional differences in the condition of a few parameters, or the relative benefit of one restoration measure over another. The Team realized this and recommended a hierarchy of reporting (table 4). Reporting must be considered in the adaptive management framework to fulfill the evaluation and assessment requirements.

A bottom up approach to indicator development would be to review the many indicators associated with ecosystem objectives; the types of indicators used to assess project performance. The Science Panel reviewed this approach at the September workshop as a potential template for tracking the achievement of individual project objectives. It has since been revised to reflect the refined objectives (table 2). The Panel notes that not all individual project performance measures may lend themselves to aggregation for reach or system-scale progress reporting. Also, we note that it is likely that there will be additional monitoring required to ensure that individual project data “connects” at larger spatial scales and contributes to the metrics for reach and system scale indicator performance evaluation.

Table 3. Ecological Endpoints, or Indicators, Developed by the UMR-IWW System Navigation Feasibility Study Science Panel (Lubinski and Barko 2003)

Biota
Low Abundance of Asian Carps
Support a Population of Lake Sturgeon
Increased Abundance of Waterfowl
Support a diversity and abundance of neotropical migrant birds
Increase freshwater mussel species diversity
Increase mast tree abundance 20-40 percent by 2050
Biogeochemistry
Meet Water Quality Criteria
Low Nutrient Concentrations in Water
Less Fine Sediment Entering the System
Manage contaminated sediments
Geomorphology
Increased topographic connections
Increased topographic variability
Decreased rates of bank erosion
Hydrology and Hydraulics
Stabilize Water Levels Below Dams
Low Water levels During Growing Season
Maintain maximum pool stage in winter
Increase flexibility of dam operations
Habitat
Maintain Aquatic Vegetation Cover in Shallow Lentic Waters
Restore Natural Terrestrial Habitat on Floodplain
Increase Special Aquatic Sites
Islands with natural habitats
Maintain current acreage of crop land in valley

Table 4. General UMRS Ecosystem Report Card Hierarchy

Audience	Parameters	Product	Timing
Technical managers and scientists	Project and reach indicators	Scientific publications and data bases	Continuing
Agencies, organizations, planners, and users	Project, reach, and system indicators	Agency-oriented program report, real-time data availability	Periodic (short) or continuous
General public and decision makers	Selected reach and system indicators	Glossy brief	Periodic (bi-annual or greater)

A top-down approach to indicator selection could be stakeholder defined. Indicators about ecosystem components valued by the public would serve as effective communication tools. Indicators may be selected for different audiences. Consider an objective for increased wetlands. This may be described as an increase in X hectares of seasonally flooded perennial emergent aquatic plants for a scientific audience, or generalized as acres of wetland for the public. Scientists may be interested in nuances of trophic production and transfer, but the public may be satisfied with the occurrence of abundant wetland species. The public has been surveyed before; their previously expressed interests (e.g. water quality) should be evident in the indicator set. The Science Panel began this process in September 2005 (table 5), but will continue through the next year as other work groups refine their recommendations.

Concerns were expressed regarding the appropriate institutional group for completing the report card. We recommend that the resulting report card framework contain explicit metrics for report card grades, such that any individual or group with access to monitoring data can assess indicator values and come to the same conclusion (grade) as another individual or institution with access to the data. The Science Panel will work with informed stakeholders to select a working set of system-wide report card indicators and metric values.

F. Discussion

Development of a Report Card process is important to NESP evaluation and communication. Knowledge of the condition and functions of the UMRS ecosystem is relatively current with the completion of the UMR-IWW System Navigation Feasibility Study, over 80 Navigation Study environmental reports, Environmental Management Program reports including the recent 10-Year Component Reports of the LTRMP and the upcoming LTRMP Status and Trends Update. The NESP can therefore concentrate on a knowledge management system that will work for the program into the future. The objectives-based decision support system will facilitate data management and access to appropriate places, scales, or parameters as it is available. The Report Card Team will continue to facilitate integrated meetings of the Science Panel to coordinate top-down and bottom-up approaches to reporting.

The Science Panel monitoring team recommends that project site-scale Project Development Teams select project objectives, indicators, and monitoring designs that fit their project evaluation needs. The Panel will assist PDTs and review individual monitoring plans to ensure they are complete, but also to be sure that appropriately scaled indicators are being measured.

G. Future Role of the Science Panel in Report Card Development

Stakeholder expectations of the Panel include monitoring study design, monitoring execution, monitoring oversight, data synthesis, and conversion of data metrics to report card scores or grades. The Report Card Team sees the role of the Panel as a technical team adjunct to the proposed River Council and extant coordination groups, River Teams, and PDTs. In this capacity, the Panel will provide recommendations for project and program performance evaluation in a hierarchal report card framework. The framework will clearly define the types of measurements to be taken to satisfy project performance, how project monitoring data fits into the overall program monitoring framework, and what ranges of monitoring results should be considered by stakeholders in establishing performance grades for selected indicators. The framework will not suggest who or what institutional element should be responsible for data collection, as the Panel envisions that to be the purview of the river management community. The Panel foresees that over time indicators, measurements or metrics, and performance results will cause periodic shifts in performance expectations and adjustments in report card elements. These adjustments would represent adaptive management in practice, and should be encouraged by participating institutions. The Science Panel in place at those points in the future will assist stakeholders in appropriate venues to interpret results, provide forecasts, and recommend adjustment in monitoring necessary to gain performance information desired at that time, reflective of evolving expectation for condition of the river ecosystem.

The Report Card Team will continue to refine appropriate lists of indicators for different audiences. We intend to make full use of previous planning products, and thereby bring supporting efforts from all partners and coordination groups into subsequent activities of the Team. The Team will introduce the process for report card development and proposed indicators to stakeholders in order to assure that their priorities are represented and to demonstrate the value and utility of public input over the years. Coordination with the Goals and Objectives, Ecosystem Services, Modeling, and Monitoring teams will be critical to assure the indicators ultimately selected are valued, understandable, and measured at the appropriate scales.

Table 5. Examples of Ecological Parameters That Can Serve As Indicators of the Status of Essential Ecosystem Components (EECs

EEC	Indicator 1	Indicator 2	Indicator 3	Indicator 4	Indicator 5	Indicator 6
Water Quality	Water clarity during the aquatic veg critical growth period, off-channel areas	# of dissolved oxygen; high risk of episodes in off channel habitats	algal blooms; nutrient flux (input & output)	fish advisories/contaminants. Sediment loading		
Geomorphology	Acres of new land after each 1-in-XX year flood	Acres of new water after each 1-in-XX year flood	hydrography - landscape metric - ?? Past condition or desired future condition.	change in floodplain elevation based, + or -. Island # and or acres	miles of flowing channels at different Qs.	Change in area of specific planform features
Hydrology/hydraulics	Selected IHA annual metrics (average daily elevation drop on descending slope of flood) (# of reversals)	A multi-year metric we believe drives floodplain vegetation diversity	Stage / Q relationship	lateral distribution of flow (%?)		
Habitat	Aquatic Qualiy: backwater depth metric	Aquatic Quantity: Side channel acres. Terrestrial Quantity: native wet meadows acres	ratio of wetted areas during high and low flows (floodplain lakes and wetlands)	mudflats	connectivity - longitudinal for species	
Biota	Resident species: # of "healthy" mussel beds, floodplain forest diversity	Migratory species:Large river obligate fishes, waterfowl use-days	acres of aquatic plants, and distribution. Measured against a planning endpoint.	Exotics, Mussels, shorebird use, rough fish/sport fish ratio	T & E species?	

5 Project Evaluation and Sequencing of Proposed Restoration Projects

A. Area of Responsibility

The Project Evaluation and Sequencing Team, (including the Environmental Management Program System Ecological Team), was charged with developing a processes to ensure that proposed ecosystem restoration projects meet ecological needs and objectives at all scales. The System Ecological Team reviews proposed project Fact Sheets and local sequencing recommendations developed by River Teams at the Corps District level. The System Ecological Team was convened to inform the UMRS Environmental Management Program, and was incorporated into the Science Panel, due to the need to evaluate, select and identify the best order for implementation of proposed ecosystem restoration projects for both the existing EMP and the proposed NESP.

B. Members

Science Panel
John Barko – USACE, ERDC, Vicksburg, Mississippi
Robert Clevenstine – USFWS, Ecological Services Field Office, Rock Island, Illinois

Environmental Management Program-System Ecological Team
James Garvey – Southern Illinois University, Fish and Wildlife Cooperative Research Unit, Carbondale, Illinois
Michael Griffin – Iowa Department of Natural Resources, Bellevue, Iowa
Carl Korschgen – USGS, Columbia Environmental Research Center, Columbia, Missouri

Support Team
Sandra Brewer – USACE, Rock Island District, Rock Island, Illinois
Kevin Landwehr – USACE, Rock Island District, Rock Island, Illinois
Roger Perk – USACE, Rock Island District, Rock Island, Illinois
Charles Theiling – USACE, Rock Island District, Rock Island, Illinois
Daniel Wilcox - USACE, St. Paul District, St. Paul, Minnesota

C. Objectives

The Project Evaluation and Sequencing Team was tasked with refining a process for selecting proposed ecosystem restoration projects and determining an appropriate sequence for implementing them for both the existing UMRS EMP and the proposed NESP.

UMRS environmental restoration activities have proceeded along a passive adaptive management process in which learning from earlier projects has been incorporated into later projects, however, there has been limited consideration of ecological monitoring and learning opportunities as factors in project sequencing. The active adaptive management process adopted for the NESP, and recommended for other UMRS activities, specifically requires that project sequencing consider the learning needs of the program. There are a number of potential strategies for incorporating experimentation and learning into a program of ecosystem restoration projects. Similar projects could be conducted simultaneously in different places with rigorous monitoring to understand the processes and responses involved. Alternatively, projects could be sequenced incrementally to understand how different combinations of management actions may achieve ecological objectives.

The Team understood administrative realities surrounding restoration project selection and sequencing, but was not asked to and did not make recommendations regarding issues like real estate, regional equity, etc., focusing instead on ecological effectiveness. The Team also understood that Environmental Management Program and NESP program managers will set final project implementation schedules based on many technical, policy, and financial considerations, as well as the ecological recommendations of the System Ecological Team or Science Panel.

D. Approach

The Project Evaluation and Sequencing Team reviewed the project selection and planning process that has evolved for the UMRS Environmental Management Program. They then considered ways to evaluate local and system-wide benefits of proposed restoration projects through an assessment of specific ecological criteria. A process in which the Project Evaluation and Sequencing Team can interact with PDTs, River Teams, and the River Council to select and sequence projects for best ecological effectiveness was the goal of the Team.

E. Results

1. Environmental Management Program Restoration Sequencing Framework

The UMRS Environmental Management Program Coordinating Committee over time has approved an incrementally refined process for habitat rehabilitation and enhancement project (HREP) selection and sequencing, with the intent to meet ecological needs at multiple scales, to make explicit and consistent decisions, and to apply adaptive management principles. The current four-stage process includes Corps, U.S. Fish and Wildlife Service, state resource management agencies, and non-governmental interests. Project ideas are first introduced to regional planning teams presently called District Evaluation Teams (equivalent to the River Teams as described in chapter above). The District Evaluation Teams decide to develop fact sheets that describe proposed projects. The District Evaluation Teams consider existing ecosystem conditions in the proposed project area, expected future conditions without restoration and ecosystem objectives in their selection of proposed restoration projects. The District Evaluation Teams evaluate local and regional benefits of proposed projects and recommend a sequence for implementing them.

The three District Evaluation Teams feed ideas and recommendations to the System Ecological Team. The District Evaluation Teams provide a checklist, developed by the System Ecological Team that summarizes criteria related to the objectives of the project. The System Ecological Team considers how well projects meet ecosystem objectives for the UMRS, their consistency with regional and National goals, whether the proposed projects are staged or coupled, incorporate natural river processes in the proposed restoration designs, and how sustainable or durable projects may be. The System Ecological Team will review fact sheets of proposed projects and proposed project sequencing and provide feedback to the District Evaluation Teams outlining factors used in the system wide sequence of projects. The System Ecological Team and District Evaluation Teams will work closely exchanging information about conditions in project areas, proposed project features, and information about logical order for implementation

A Program Planning phase introduces the administrative considerations of what system wide mix of projects is better than each individual project alone. The program planning produces a Habitat Rehabilitation and Enhancement Projects Program Plan based on the high priority projects proposed by the District Evaluation Teams and SET. Other administrative considerations include:

- Combination of innovative and proven techniques
- Variety in types of management actions
- Geographic distribution
- Annual funding
- Maintaining minimum District implementation capability
- Cost sharing, leveraging non-Environmental Management Program funds
- Public support
- Readiness (NEPA, permits, land availability)
- Leveraging non-EMP funds
- Compatibility with other river uses
- O&M requirements and opportunities for aligning with O&M activities

Program planning will first select which projects are forwarded for detailed planning, and also determine the construction sequence of approved projects.

In the Environmental Management Program, the Mississippi Valley Division retains the ultimate responsibility and final approval authority for all programming and budgetary decisions. The NESP authorization will, presumably, have similar policy for routine actions, but will require Headquarters review for large experimental actions like fish passage.

2. Ecological Evaluation Considerations

The Project Evaluation and Sequencing Team further refined the evaluation criteria matrix. The Project Evaluation and Sequencing Team and System Ecological Team worked to add, reorganize, and score criteria. One version of the matrix included scored and weighted criteria for Environmental Management Program Habitat Needs Assessment objectives, ecological criteria, and non-ecological factors. The scoring, and especially importance weighting, was met with skepticism by stakeholders in initial reviews. Science Panel members were concerned that proposed projects could be “loaded” to maximize the number of objectives addressed. Most ecological criteria can only be considered subjectively for projects proposed in concept, and there is presently no good way to quantitatively assess the degree to which proposed projects may contribute to attaining the ecological objectives at different scales. Also, some management actions have a more diverse and extensive effects than others, regardless of local opportunities or needs. There is a valid concern that some river reaches don’t have the same diversity of habitat and thus have less opportunity to meet some objectives.

The Project Evaluation and Sequencing Team organized a review of criteria among seven ecological considerations:

1. Ecological merit/benefits
2. Attention to restoration of natural processes & features
3. Benefits over multiple scales of time and space
4. Critical habitat gains
5. Sustainability projections
6. Contribution to learning via monitoring and experimentation
7. Compatibility with existing plans.

Ecological merit is the degree to which a proposed project may contribute to attaining ecosystem objectives. Ecological benefit was defined as the increase in ecological services (drinking water, flood attenuation, recreation, aesthetics, etc.) that a project may provide, or the value of such services. This category was eliminated from the final matrix in part because it was duplicative of the longer list of natural processes and compatibility with existing plans. The estimates of benefits are also very subjective, given that projects in concept are being evaluated and because of limited predictive capabilities. More explicit models linking management actions to ecological outcomes are required to quantify the ecologic and economic outcomes of restoration activities.

Consideration of natural processes and features has been part of all UMRS environmental restoration activities, whether explicit or not. The simulation of complex ecological interactions, however, is difficult. The Navigation Study Science Panel recommended a mix of conceptual and numerical models that might eventually achieve this. In the meantime, a set of Ecological Process and Feature criteria (table 6) are proposed for consideration as a checklist for evaluating proposed projects. The process criteria are the types of drivers, processes, communities, and organisms in the UMRS conceptual model (Lubinski and Barko 2003). The criteria are defined in Appendix B.

Some projects may have benefits that extend over multiple spatial scales. Examples of benefits that span spatial scales include: creating feeding areas for migratory waterfowl, fish passage improvements, or restoring the delta area of a major tributary. Some project types or groups of projects may achieve synergistic or cumulative benefits. Temporal scales involve not only the timing of construction, but also the time it takes for ecological response and benefits to be achieved. Bottomland hardwood forests, for example, take decades to mature whereas a channel structure may induce habitat change nearly instantaneously. Natural temporal patterns and connectivity are important considerations in restoration project selection and sequencing.

The critical habitat gains criterion is to assess how projects may contribute to restoring historic, maintain existing, or improve future habitat types over current or reference conditions. While all proposed projects, arguably, address important habitats, this criterion is to ensure that PDTs carefully consider the desired future conditions for project sites, river reaches, or regions.

Contributions to learning are cornerstone considerations in an adaptive management program. There have been many lessons learned through passive adaptive management over time, but a rigorous adaptive management program requires planned experimentation and learning. Restoration projects can become learning opportunities by incorporating an experimental technique or technology, being part of a larger experimental design, incorporating effective monitoring, resulting in increased ecological understanding, or result in management innovations.

Sustainable and durable projects are accomplished through a mix of incorporating natural processes that don't require maintenance. Constructed features have to be durable over time in the dynamic river environment. Projects should require minimal operation and maintenance costs and total project costs should be commensurate with benefits (increased ecosystem services). The predictability and persistence of project outcomes over time are also important criteria. We believe that projects incorporating natural processes will generally satisfy these criteria.

Compatibility with existing plans is a relatively simple activity of reviewing which ecosystem objectives of other plans may be achieved by a NESP project.   Demonstrated compatibility with existing plans of other agencies and organizations is important for both regulatory compliance and support for proposed projects.

3. Criteria Scoring

As noted earlier, there have been prior attempts to evaluate projects using scored or ranked criteria. The System Ecological Team and Project Evaluation and Sequencing Team were not enthusiastic about the approach, especially when factor weighting was proposed. Scoring projects that are slightly more than ideas or concepts during early planning stages seemed too rigorous.

The System Ecological Team and Project Evaluation and Sequencing Team decided that the individual criteria under each ecological consideration category would be evaluated in a binary fashion, at least initially during a period of "testing". Proposed projects would be checked, or scored, if they would affect the criteria. Scored criteria could be summed within classes of ecological consideration to compare projects more broadly.

Table 6. Ecological Evaluation Criteria Associated With UMRS Ecosystem Restoration and Management Actions

	Floodplain Forest and Grasslands Restoration	Islands Building	Fish Passage Improvements	Floodplain Connectivity Restoration	Water Level Management	Secondary Channel Restoration	Backwater Restoration	Wing Dam, Closing Dam Modifications	Island and Shoreline Protection	Floodplain Topographic Diversity Restoration	Change River Regulation to Dam Point Control	Dam Embankments Modifications	Reduce Illinois River Water Level Fluctuations
Ecological Consideration													
Contribution To Leaning													
Incorporates an experimental approach	√	√	√	√	√	√	√	√	√	√	√	√	√
Fits within experimental design/approach	√	√	√	√	√	√	√	√	√	√	√	√	√
Incorporates effective monitoring plan	√	√	√	√	√	√	√	√	√	√	√	√	√
Likely to result in fundamental knowledge gain	√	√	√	√	√	√	√	√	√	√	√	√	√
Likely to result in management innovations	√	√	√	√	√	√	√	√	√	√	√	√	√
Benefits Over Multiple Scales													
Improves connectivity laterally	√	√		√		√	√	√			√		
Improves connectivity longitudinally	√		√									√	
Achieve cumulative/synergistic habitat improvements (greater than additive)	√	√	√	√	√	√	√	√		√	√	√	√
Emulate natural temporal patterns	√	√	√	√	√	√	√	√		√	√	√	√
Sustainability													
Requires minimal on-going intervention to maintain desired future state	√	√	√			√		√	√	√	√	√	
Scale of maintenance activity is small relative to overall project activities.	√	√	√	√	√	√	√	√	√	√	√	√	
Improves stability of project outcomes/services	√	√	√	√	√	√	√	√	√	√	√	√	√
Restores natural river processes		√	√	√	√	√	√	√		√	√	√	√

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Critical Habitat Gains													
Replaces lost habitat (i.e. historical assessments)	√	√	√	√	√	√	√	√		√	√	√	√
Maintains desirable habitat	√				√	√	√		√		√	√	
Modifies or improves existing conditions	√	√	√	√	√	√	√	√	√	√	√	√	√
Meets the desired future condition	√	√	√	√	√	√	√	√	√	√	√	√	√
Compatibility With Existing Plans													
Habitat Needs Assessment	√	√	√	√	√	√	√	√	√	√	√	√	√
UMRCC Objectives	√	√	√	√	√	√	√	√	√	√	√	√	√
UMR-IWW Environmental Objectives	√	√	√	√	√	√	√	√	√	√	√	√	√
MMR Side Channel Plan	√	√				√		√	√				
MMR Dike Plan	√	√				√		√	√				
Illinois Ecosystem Study/IL2020	√	√	√	√		√	√			√			√
USFWS-NWR CCPs	√	√	√	√	√	√	√	√	√	√	√	√	√
State Management Plans	√	√	√	√	√	√	√	√	√	√	√	√	√
Other Conservation Plans (NAWMP, Joint Venture, Shorebird Plan, etc.)	√	√		√	√	√	√			√	√		√
Add other plans as required													

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Ecological Process and Features													
Geomorphology													
Channel formation		√	√			√		√	√			√	
Channel sedimentation		√			√	√		√		√		√	
Channel migration		√				√		√	√	√			
Filling between wingdams		√				√		√	√	√			
Island erosion	√	√				√		√	√	√			
Backwater formation				√		√	√	√			√		
Backwater sedimentation	√						√			√		√	
Bathymetric diversity		√		√		√	√	√				√	
Sediment quality		√		√	√	√	√	√					
Backwater delta formation		√		√		√	√			√			
Tributary delta formation	√	√		√			√		√	√			
Wind-wave erosion of islands	√	√				√	√		√	√			
Island dissection	√	√				√		√	√	√			
Island formation	√	√			√	√				√			
Island migration	√	√				√			√	√			
Topographic diversity	√	√		√		√	√			√			
Upland watershed dynamics				√			√						√

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Water Quality														
	Water clarity		√		√	√	√	√				√	√	
	Suspended sediment		√		√	√		√		√				
	Nutrients		√		√	√		√				√	√	
	Chlorophyll		√		√	√		√				√	√	
	Oxygen		√		√	√	√	√	√			√	√	
	Natural toxicity (e.g., ammonia)		√		√	√		√	√				√	
	Contaminants													
	Temperature		√		√		√	√	√				√	
Habitat														
	Diversity	√	√		√	√	√	√	√	√	√	√	√	√
	Quality	√	√		√	√	√	√	√	√	√	√	√	√
	Abundance	√	√		√	√	√	√	√		√	√		√
	Distribution	√	√		√	√	√	√	√		√	√	√	√
	Patch size	√	√		√	√	√	√	√		√	√	√	√
	Corridor	√	√	√	√	√	√	√	√		√	√	√	√
Ecosystem														
	Primary production	√	√		√	√	√	√			√	√	√	√
	Carbon sequestration	√	√		√	√		√			√	√	√	√
	Proximity of critical habitat	√	√	√	√	√	√	√	√	√	√	√	√	√
	Proximity of life requisite habitat	√	√	√	√	√	√	√	√	√	√	√	√	√
	Ecosystem engineers (e.g., beavers, carp, etc.)	√			√		√	√				√		
	Nutrient transformations and cycling	√	√		√	√		√	√		√	√	√	√
	Biogeochemical processes	√	√		√	√		√	√		√	√	√	√
	Disturbance	√	√	√	√	√				√	√	√	√	√

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Biota															
		Terrestrial Plant Communities	√	√		√	√				√	√	√		√
		Aquatic Plant Communities		√		√	√		√				√	√	√
		Migratory Waterbirds	√	√		√	√		√		√	√	√	√	√
		Neotropical Migrants	√	√		√	√		√		√	√	√	√	√
		Terrestrial and Semi-Aquatic Resident Wildlife	√	√		√	√		√		√	√	√	√	√
		Amphibians and Reptiles	√	√		√	√		√	√	√	√	√	√	√
		Backwater Fishes		√	√	√	√	√	√	√			√	√	√
		Riverine Fishes		√	√			√	√	√			√	√	√
		Freshwater Mussels		√	√			√						√	
		Aquatic Macroinvertebrates		√		√	√	√	√	√			√	√	
		DNA/Biodiversity/Genetic Vigor	√	√	√	√	√	√	√	√	√	√	√	√	√
		Exotic species	√		√										
		Disease/parasites	√		√										
	Hydrology and Hydraulics														
		Water stage regulation	√			√	√						√	√	√
		Floodwater distribution	√			√							√	√	√
		Flow distribution		√	√		√	√		√	√	√	√	√	√
		Water retention time	√	√		√	√	√	√	√			√	√	√
		Isolation/desiccation		√		√	√	√	√	√			√	√	√
		Wind Fetch		√					√		√				
		Water table/Groundwater	√			√	√					√	√		√

4. Project Sequencing Criteria

Project sequencing is not done by a strict review of evaluation criteria alone. There are administrative issues mentioned earlier, but there are also additional specific ecological criteria that may determine the priority of projects. Ecological Sequencing criteria considered by the Project Evaluation and Sequencing Team include:

- Minimum habitat requirements
- Temporal considerations/dependencies
- Spatial considerations/dependencies
- Bioenergetics
- Functional diversity
- Structural diversity

These criteria were included because they incorporate large scale ecological process and population effects of projects.

Minimum habitat requirements is a population criteria included to assess habitat requirements of target species or guilds. Habitat requirements frequently differ among season and life stage, thus, this criterion also incorporates seasonal and life stage habitats. Habitat requirements can be and are frequently generalized, but the specific habitat requirements, and especially details like carrying capacity, are not well known for most species. Habitat requirements can be modeled, but the strength of the models is rather weak at this time. There is great opportunity to investigate these issues under the proposed adaptive management framework.

Temporal considerations/dependencies include the construction sequencing of large numbers of projects whose ecological response may take decades and may require the interactions of many complex ecological processes. For example, land may be converted from agriculture to bottomland hardwood forest plantings that take decades to mature given that they are not flooded, eroded, eaten, diseased, etc. The positive outcome depends on favorable hydrologic conditions and a certain amount of maintenance. Other projects may be more explicitly dependent such as a dredging and island building action; material to build islands is borrowed from new or restored channels oriented to overflows such that they receive scouring flows. The dependencies in construction materials and long term sustainability through design of project features are explicit, but there is also finer scale geomorphic succession over time and plant community succession that may take many years to develop.

Spatial considerations are similar to the temporal considerations in terms of the construction of features and distribution of seasonal habitat. There are frequently project features whose construction is linked to another project feature, like a control structure in a levee or island fill material obtained from an adjacent deepwater habitat objective. The distribution of habitat can range from local scales like open water and vegetated portions of a single backwater, for example, or regional or continental scales like the distribution of wetlands at an appropriate distance along a migration route. A large landscape scale dependency is the maintenance of specific habitat patches at appropriate distances or locations along migration corridors or to maintain regional populations. Habitat requirements of birds may be best understood, some requiring large forest blocks, others using edges, others in prairies, etc., the range of fish and wildlife habitat requirements, however, is extensive and poorly understood for many target species.

Functional diversity refers to the range of ecosystem processes important to creating and maintaining diverse river habitats. Many of these functions are listed in the natural process criteria described earlier (table 5). They are the geomorphic processes that form river habitats and the biological processes that grow plants, reproduce populations, and recycle nutrients. Creating and maintaining these processes is critical to the success of river restoration activities. It is difficult to itemize ecological functions without a good understanding of specific site characteristics.

Structural diversity is the mix of physical and plant community characteristics at a site. Water depth, terrestrial features (i.e., ridges, swales, etc.), islands, floodplain connections, forest characteristics and many, many other features affect the structural diversity at a site. Creating and maintaining this physical diversity is critical to the success of river restoration activities. It is difficult to itemize structural diversity without a good understanding of specific site characteristics.

5. Project Sequencing Approaches

Each evaluation consideration is important, but their relative importance in addressing a project or a set of projects changes in light of the needs and opportunities at the time of construction. Realistically, funding can dictate the options of how to sequence projects. In a funding scenario like the Environmental Management Program, Project Managers respond to a set of projects approved and forwarded by District teams. In this case, the Critical Habitat, Sustainability, and Benefits Over Multiple Scales criteria may outweigh the Contribution to Learning criteria because of limited funding. The mix of processes addressed in this process would be limited to those available at sponsored project locations. Under a high funding scenario envisioned for NESP, the Contribution to Learning and mix of Ecological Process and Features become more important as sequencing considerations. Projects could be selected to investigate specific geomorphic processes in specific regions to build and refine models for instance. Alternatively, a river reach restored through a mix of projects that could be investigated to assess the relative or synergistic impact of incremental habitat restoration actions. A high funding scenario increases opportunities for Active Adaptive Management.

6. Current Sequencing Approaches

The Environmental Management Program Habitat Rehabilitation and Enhancement Projects have been restoring river floodplain habitat at a rate of approximately $10 million per year since 1988. Completed projects address many high priority environmental management needs, but there are many objectives remaining. Project sponsors and the Corps continue to work through the sequencing framework described above to address the remaining objectives. Priority projects are initiated at a rate of 3 – 5 active projects per year, with most taking more than one year to build. Projects have included a variety of restoration approaches throughout the river system. Some restoration practices have been emphasized regionally where they are suited to regional geomorphology and hydrology.

Critical habitat desires of project sponsors were primary drivers in Habitat Rehabilitation and Enhancement Projects sequencing. There were considerations for learning, and projects became more sustainable over time with experience and learning. Regional and system scale influences or contributions are only recently being emphasized. There are opportunities for continued learning, but the rate of learning may be very slow as it is tied to the rate of project construction. Projects typically take 5 to 10 years to plan, sequence and build; thus, the learning process may be quite slow and unsatisfactory.

Several restoration actions have been implemented and refined through a passive adaptive management approach under the Environmental Management Program. Island design and construction is the best example of doing and learning in the UMRS, and there are also many other restoration actions that have been designed and refined through field experience. However, Ecological response monitoring, especially large-scale regional response, has not been effectively incorporated into the Environmental Management Program. The monitoring, evaluate, and adjust components of the adaptive management loop have been completed for only a few measures. Aquatic plant and fish sampling at island projects led to design changes that greatly increased the local area benefited by individual projects. Waterfowl monitoring in backwater wetland restoration identified rapid response of waterbirds to improved habitat in specific backwaters. Fish response to many projects, however, is not well understood and it has not been determined if local or regional populations of most restoration targets have benefited from multiple restoration measures.

7. Future Approach to Project Selection and Sequencing

Active adaptive management can be best executed with attention to all components of the adaptive management process and sufficient funding to implement, monitor, and evaluate responses from a number of projects in a timely manner. It is also critical to coordinate activities to maximize the cumulative learning benefits of projects across programs and agencies. It is important to have several examples of each type of restoration project to determine if there are common responses, how features function in different settings, etc. It would be best if these evaluations could happen rapidly to incorporate the results into subsequent projects. It is also important to understand pool or reach-scale ecological responses to multiple restoration projects. Learning opportunities become more important project sequencing considerations in a well-funded adaptive management framework.

The current state of knowledge of common restoration activities varies (table 7). Restoration actions that are well understood and documented can be implemented at a faster rate because the planning and regulatory processes can proceed under programmatic authorities. Restoration actions that are untested or innovative need to be more fully evaluated through the adaptive management process. There are, of course, actions for which the physical responses are understood and the biological responses are not.

Table 7. Learning Status, or State of Knowledge, of Common Ecological Restoration Activities Considered for the UMRS

	Learning Status	
Management Action	Physical	Biological
Floodplain Forest and Grasslands Restoration	Low	Moderate
Islands Building	High	Moderate
Fish Passage Improvements	Low	Low
Floodplain Connectivity Restoration	Moderate	Low
Water Level Management	Moderate	Moderate
Secondary Channel Restoration	Moderate	Low
Backwater Restoration	Moderate	Moderate
Wing Dam Modifications	High	Mod
Island Protection	High	High
Shoreline Protection	High	Mod
Floodplain Topographic Diversity Restoration	Moderate	Low
Change River Regulation to Dam Point Control	Moderate	Moderate
Dam Embankments Modifications	Low	Low
Reduce Illinois River Water Level Fluctuations	Moderate	Moderate

A sequencing alternative emphasizing learning could complete the biological response evaluations of restoration activities for which the physical response is known, thus completing the adaptive management loop. Learning physical and habitat responses could also be initiated on common projects types that have not been adequately evaluated. Biological responses could be inferred from habitat changes until later, as they have been, or they can be studied concurrently with physical monitoring. New actions should proceed along an adaptive management framework if they are to be implemented. Under a learning framework, regional performance of restoration actions would also be considered, but implementation sequencing must be appropriate to accomplish work in several regions at approximately the same time.

A sequencing alternative that emphasizes benefits over multiple scales would incorporate a more systemic landscape perspective than site-driven approaches. Habitat patch distribution and connecting corridors are important considerations, and they must incorporate a great diversity of species requirements. Issues of habitat succession and dynamic sustainability through river reaches and the system are important for many of the long distance migrants as well as resident species.

Project sustainability remains a consideration of all projects rather than a focus of the program. The Environmental Management Program has shown how construction activities and features can be optimized through experience. Critical habitat gain also remains an important consideration. The distribution of wetlands or backwaters may be strong determinants of local populations. On a system or regional scale, however, it may be that some locally unpopular projects may need to be conducted for a systemic benefit. A degraded backwater lake, for example, may be converted to marsh habitat rather than restored to the former lake habitat despite local desires for a backwater lake.

8. Learning Needs

In a large-scale, long-term program like the NESP, it is imperative to learn early and execute efficiently in the future. The summary of learning status (table 6) and an understanding of regional ecological issues can help guide project sequencing. There is a range of learning needs (table 8) among the common restoration activities. The status of our state of knowledge and information needs for common restoration activities are discussed very briefly below. This review provides an idea of the range and types of issues that should be considered in a robust adaptive management strategy. The review reflects unbiased opinions of the Science Panel, albeit in some cases based on limited science, and it is recognized that these opinions may not be endorsed by all river restoration practitioners.

Table 8. Learning Needs of Common Ecological Restoration Activities Considered for the UMRS

Management Action	District	Learning Need
Floodplain Forest and Grasslands Restoration	All	Successional model, Landscape analysis
Islands Building	All	Soft sediment construction; New island construction
Fish Passage Improvements	All	New – begin Adaptive Management
Floodplain Connectivity Restoration	MVR	Fish movement; Animal populations
Water Level Management – Backwater	MVR/MVS	Fish response; Animal populations
Water Level Management – Pool	All	Animal response; Population response
Secondary Channel Restoration	All	Animal response; Population response
Backwater Restoration		Dredge technology; Physical sustainability, Animal response; Population response
Wing Dam Modifications	MVS	Animal response; Population response
Island Protection	All	Targeting
Shoreline Protection	All	Targeting
Floodplain Topographic Diversity Restoration	All	Succession, Landscape analysis
Change River Regulation to Dam Point Control	MVS	Animal response; Population response
Dam Embankments Modifications	MVP	Animal response; Population response
Reduce Illinois River Water Level Fluctuations	MVR	Habitat response; Animal response; Population response

Island projects in the USACE St. Paul District are physically well understood and some biological responses have been documented. The reach and regional population responses, however, are not documented. It is not well understood whether biological responses are the product of attraction or increased production. It may be that production driven responses take some time to be exhibited; this need for learning is common to many other restoration actions as well. Soft substrate island construction techniques are not well understood or widely practiced. Innovative material handling is expanding opportunities. A careful investigation of alternative dredging techniques and their biological outcomes should be undertaken during NESP. Island construction in the Unimpounded Reach can incorporate natural processes to form new islands and secondary channels. Experience with regulating structures has demonstrated these types of activities can be quite successful. As above, these island-forming activities should be encouraged and evaluated.

Land management for wildlife habitat has a relatively long experience in the UMRS and elsewhere. Planting, harvesting, burning, and water level manipulation are all common tools used to manage habitat in many areas. Large landscape scale habitat distribution and plant community succession has not been a strong consideration in regional planning. Although there are regional conservation and land management plans, implementation has been locally opportunistic rather than regionally driven. There are obvious differences in the distribution of opportunities, both spatially in terms of real estate ownership, hydrologic regime and edaphic factors throughout the system.   A system-scale landscape assessment and a floodplain vegetation successional model adapted to different parts of the river system would be very useful in planning floodplain restoration projects.

Fish passage is a long-standing concern on the UMRS, but there is very limited understanding of UMRS fish movements. Because this is a new restoration action, never done on the UMRS, it will benefit from being conducted within the adaptive management framework. The fish passage projects will need to have clear ecological and learning objectives. Monitoring plans currently being developed include monitoring to gain information needed for project design, monitoring to determine the numbers and species of fish passing through the dams under existing conditions and the additional number and species of fish that will pass through fishways. More difficult and long-term monitoring may reveal geographic range expansions and population response of migratory fishes and associated mussel species. Science and stakeholder review is strongly emphasized.

Habitat response to connectivity between the rivers and floodplains is generally understood, and a number of projects have had objectives to modify lateral connectivity. Site specific conditions determine the range of opportunities which might not achieve the desired condition because of factors beyond the site. The influence of these projects on the river ecology, whether it is fish movement, energy transfer, river stage, or sedimentation is more difficult to determine. Because there are relatively few opportunities for new floodplain connections, they should all be monitored rigorously. New and existing projects of this kind could be included in a monitoring and evaluation design to increase sample size. Preliminary analyses during the UMR-IWW System Navigation Feasibility Study indicated that modifying floodplain connectivity is a very effective restoration approach with potentially broad ecosystem response.

Water level management is a component of many restoration projects. These activities have been ongoing by state and federal wildlife managers for more than 50 years. Vegetation and waterfowl responses are quite well known, fish and non-game species responses are not so well known. Habitat changes are generally easy to detect through remote sensing, so modeling biotic response to habitat may provide cost effective monitoring methods in the future. Pool scale water level management was effectively designed, implemented, and monitored through the adaptive management framework in the St. Paul and St. Louis Districts. While biotic responses require more monitoring and modeling, known habitat responses could be summarized or referenced from prior work.

Physical aspects of secondary channel restoration are fairly well understood and highly refined site data and mathematical hydraulic and water quality modeling can predict outcomes to restoration actions quite well. New ideas for side channel and island creation in the Unimpounded Reach are exciting but they all work on about the same physical principals. The scale of physical action and biotic response, however, may be markedly different between locations, and will need to be evaluated separately and compared later. The biological baseline in many cases is poorly understood in open channels, which makes it difficult to predict biological outcomes at this time.

Backwater restoration can mean many things, but typically refers to dredging deepwater habitat, constructing islands, and manipulating inflows and outflows to balance oxygen requirements. It could also be one of the most repeated and, overall, expensive measures attempted through NESP. Dredging is sometimes the main feature of a project, but it is also a component of many projects. Recent backwater restorations have met with success in terms of biological and public response, but many dredged areas are filling more rapidly than anticipated. Ecological response monitoring has demonstrated local responses within project areas, and it has been very popular with the public. It is important that ecological response monitoring and evaluation continue in the future. It is also necessary to make use of new dredging capabilities as they are introduced. Combined project features like temporary drawdowns coupled with excavating may prove to be efficient. Dredge cut orientation to flow and sediment transport processes may lead to effective design criteria. Sediment transport modeling may prove very helpful to project design.

Bank stabilization, island protection, and channel regulating structures are very well understood in concept and have been widely applied throughout the UMRS. Biological communities associated with these structures are also relatively well understood. Questions remain regarding the finer aspects of habitat use, but also on a broader scale of what should the spatial distribution of these actions be? There should be consideration of armored vs. natural banklines and continued small-scale changes in river plan form. They are relatively economical measures that can be applied on a wide scale, rapidly by work crews already on the river for channel maintenance activities.

Modifying floodplain topographic diversity is a measure used to improve survival and rooting conditions for less flood tolerant mast-producing tree species, like oaks, pecans, and hickories that are important to floodplain wildlife. The measure is a relatively simple activity that can be incorporated with many other floodplain restoration and channel maintenance activities. Evidence shows that some former dredged material disposal sites become rapidly vegetated if overlain with finer-grained material, while uncapped dredged material placement sites revegetate slowly and may remain exposed sand. Learning opportunities regarding soil preparation, planting elevation, species, and stock survival, etc. abound. Foresters and forest ecological modelers need to work to assess current forest/landscape conditions, responses to restoration, and regional desired condition to establish achievable objectives.

Dam embankment modifications are meant to protect the structural integrity of the embankments, increase hydrologic connectivity between navigation pools and to provide improved habitat conditions in the impounded area of the pools adjacent to the embankments. The hydrology and hydraulics, as well as the structural engineering, are quite straightforward, but very site-specific. Water quality and animal responses could be predicted then monitored to validate predictive models. Benefits to fish migration could also be predicted in a modeling context and then evaluated through monitoring. The measure presents new opportunities to evaluate fish movement and populations, but is similar to other backwater restoration efforts and could be included in the backwater restoration monitoring framework as well.

Illinois River hydrology is significantly altered by mainstem and watershed development. Unseasonal floods are responsible for limiting moist soil plant production in the low elevation shoreline areas where water levels vary frequently. Actions to reduce water level fluctuations could achieve many of the wetland restoration benefits of water level management and floodplain restoration actions, but the effects would be large scale and widespread. Response monitoring would require system-wide remote sensing for habitat response and broad trend monitoring to detect change because the response would be diffuse along long extensive backwater and channel shorelines.

F. Integration Plan

The ecological considerations established for project evaluation and sequencing illustrate the links to other issues being reviewed by the Science Panel. The contribution to learning criteria demands monitoring and evaluation, and to enhance learning and predictive capabilities, outcomes should be modeled. Sequencing logically considers benefits over multiple scales and compatibility with existing plans as regional recommendations are reviewed and integrated to achieve system-wide goals and site objectives. Modeling can be used to evaluate integrated plans and predict outcomes such as achievement of critical habitat gains and increases in ecosystem services.

During NESP implementation, the project evaluation and sequencing team will work with local river managers to understand regional objectives, projects, and their ecological justifications. They will then incorporate those along with recommendations from other regions. Coordination with modeling and monitoring teams may influence the project site or management action selection to satisfy learning needs or desired ecological services. The ecological sequencing team will forward implementation alternatives to the River Council.

G. Discussion

Navigation pools and river reaches are the appropriate scale for PDTs to conduct planning for restoration activities. River Teams and PDTs have the local knowledge required to understand ecosystem problems and restoration opportunities. Their restoration project recommendations will emphasize priority sites and sequence of restoration activities.

River Team and PDT recommendations, along with the entire set of ecosystem objectives, will form the basis for Science Panel deliberations. The Science Panel can evaluate the system-wide implications of recommended projects, their geographic distribution, the degree to which they meet the entire suite of ecosystem objectives established by stakeholders, and the degree to which they would contribute to learning in the adaptive management process. The Science Panel can then recommend sets of projects, immediate need, near-term need, and far-term need, to the Corps for coordination with stakeholders. The Science Panel will work with the UMRS partnership to clarify an overarching restoration philosophy for the UMRS. This is essential to guide system-wide selection and sequencing of restoration effort.

H. Future Role of the Science Panel in Project Sequencing

The Science Panel Evaluation and Sequencing Team will provide tools for recommending an initial set of projects. The Panel will work from lists of projects forwarded by the River Teams and reach planning PDTs. The Science Panel will review changes in the partnership’s ecosystem objectives, gains in ecological understanding from monitoring and modeling, and adapt to new information as the program proceeds. As goals and objectives, particularly at the system scale, become better formulated and established, the Science Panel will become more effective working with river resource management teams in project sequencing.

6 Monitoring

A. Area of Responsibility

The Monitoring Team was responsible for developing guidance on how UMRS managers can develop data and knowledge to evaluate the success of environmental restoration efforts and to improve the ecological effectiveness and cost efficiency of the program.

B. Members of the Monitoring Team

Science Panel
Barry Johnson – USGS, Upper Midwest Environmental Science Center, La Crosse, Wisconsin
Michael Davis – Minnesota Department of Natural Resources, Lake City, Minnesota
David Galat – USGS, Cooperative Research Units, University of Missouri, Columbia, Missouri
Kenneth Lubinski – USGS, Upper Midwest Environmental Sciences Center and The Nature Conservancy, La Crosse, Wisconsin

Support Team
Thomas Keevin – USACE, St. Louis District, St. Louis, Missouri
Charles Theiling – USACE, Rock Island District, Rock Island, Illinois
Daniel Wilcox – USACE, St. Paul District, St. Paul, Minnesota

C. Objective

The Monitoring Team was tasked with developing recommendations for a monitoring program that provides data to:

- address the level of success in achieving Program objectives at both local and larger scales;
- communicate that success through a report card that rates the condition of the UMRS; and
- increase our understanding of ecosystem processes through data analyses and modeling.

D. Approach

The NESP is an ambitious program with many different monitoring needs. The Program is being implemented under an adaptive management framework which has evaluation and learning as a cornerstone. Monitoring needs range from the local or site level related to projects to the reach or system level for large scale goals. The Science Panel, working in conjunction with the PDTs and River Teams, should provide guidance on how monitoring effort can be used most effectively, considering the learning potential for individual and multiple projects and the need for evaluating success in achieving Program goals.

This chapter evaluates monitoring needs for adaptive management including local effects of individual projects, cumulative effects of multiple projects, reach scale monitoring, and system scale monitoring. The chapter also discusses the role of monitoring in documenting and reporting ecosystem status and in supporting modeling efforts. The chapter lastly identifies the role of the Science Panel in future monitoring efforts.

E. Integration Plan

Monitoring must be closely integrated with all other components of the UMRS adaptive management plan because it is the key to the evaluation and learning portion of the adaptive management loop. Project and system-level objectives must be identified to determine appropriate indicators to monitor. The sequence in which some restoration projects are implemented and monitored should be considered to help maximize our ability to learn from the projects and to optimize use of the monitoring effort. Monitoring will be reported at many different levels ranging from site-specific results to assessments of the entire UMRS. Monitoring and modeling are inextricably linked. Data from monitoring and research provide the information to build initial models and later to evaluate model predictions. The monitoring and modeling loop is especially important during the early stages of the NESP to improve models so that future outcomes may be better estimated and less effort will be required to document them.

F. A General Approach to Developing Monitoring Plans

The primary goal of UMRS stakeholders is developing the management capability to sustain ecological health and socioeconomic viability of the Upper Mississippi River System. The ecological degradation currently seen in the system has resulted not from any one event or cause, but rather from a variety of modifications to the river, floodplain, and watershed. Likewise, restoration will result not from a single project or effort, but will derive from the combined effects of many different management actions including restoration projects, changes in operation of the navigation system, water quality improvements, and changes in land use within the basin.

Meeting the overall goal of sustainability will require new information on how management actions affect river processes and, ultimately, ecological and socioeconomic outcomes. Gathering new information will require a combination of research, monitoring, and analyses designed to address critical questions through an adaptive management approach. There are many potential types of monitoring (table 9), most of which will apply at some level within the adaptive management plan for the UMRS ecosystem.

Achieving the monitoring objectives above will require monitoring at different levels that focus on different spatial and temporal scales. We can define at least four scales for monitoring (table 10) that address a hierarchy of goals and objectives, which build to the overall goal of a sustainable ecosystem. The four scales include the local scale of individual projects; the navigation pool/reach scale where the interactive effects of multiple projects occur; the floodplain reach scale which is affected by cumulative effects within multiple pools or reaches; and the system-scale that exhibits the overall effects of management actions conducted through out the river corridor and basin.

Table 9. Categories of monitoring. Measured parameters may be physical, chemical, or biological, and may reflect condition or function. Source: D. Allan, NRRSS, in preparation.

Category	Scale of Monitoring within NESP [1]	Purpose
Baseline monitoring	L, P, R, S	Characterize existing conditions, including natural variability; establish a database for planning or future comparisons; use as a reference of either existing or undisturbed conditions.
Status & trend monitoring	P, R, S	Evaluate state of system over time, with emphasis on "trends". Key issue is change of conditions over time. May or may not be related to specific project or question.
Implementation monitoring	L	Evaluate whether the restoration practices were carried out as planned. Includes monitoring of construction impacts, constructed features, and characterizing immediate post-project conditions.
Effectiveness monitoring	L, P, R, S	Evaluate whether the restoration practices met stated objectives. May be directed at an individual project or a coordinated suite of multiple projects. Typically requires information about baseline and reference conditions, or desired state of system.
Validation monitoring	L, P	Advance knowledge of underlying cause and effect relationships. Use demonstration projects to strengthen scientific basis for particular restoration approaches. Monitoring data used to validate models.
Compliance monitoring	None	Determine whether specific water quality or ecological integrity criteria are being met, as specified in some environmental standard, regulation, or law.

[1] L = local or project scale; P = navigation pool or multiproject scale; R = floodplain reach; S = system wide.

Table 10. Possible Levels of Monitoring for the Upper Mississippi River System, With Basic Objectives at Each Level

Scale of monitoring	Type of objectives
Floodplain reach & System-wide	• Measure indicators of system health within major floodplain reaches.
Navigation Pool or Reach	• Measure indicators of system health within reaches of the system. • Determine effect of multiple projects within a reach.
Multiple projects	• Determine interaction among multiple projects of different types. • Assess incremental effects of multiple projects of the same type. • Assess role of different factors in success of specific restoration techniques
Individual projects	• Determine if project was built as designed and is operating as designed • Determine if project produced the anticipated local effects

Through a combination of local and large scale monitoring, we can identify which management techniques are most effective in the long term. Spatially, a project may achieve local objectives, but may have little or no effect at larger scales. For example, does constructing islands increase production of fishes within a pool or just concentrate existing fish? Temporally, monitoring designs need to consider the amount of time it may take for slowly changing variables to respond, such as changes in fish populations or communities. In addition, monitoring should be designed to determine how long near-term effects last, such as the number of years that increased plant growth persists following a drawdown. Large-scale effects will generally take longer to develop and longer to detect than local effects.

Monitoring for large-scale effects can be more difficult than for local effects because the ecological linkages become more complicated as offsite factors influence target processes and biota. The benefits of improved habitat in one location may be counteracted by degradation at another location, thus showing no overall benefit at large scales. In addition, monitoring at large scales can involve changes in underlying conditions over time or space, and be very labor intensive. Where possible, we should try to link site specific monitoring and large scale information needs. In some cases, large scale monitoring may be just an extension of local monitoring in space or time. But for some issues, large scale monitoring will likely involve designs and procedures that are separate from site specific monitoring and that extend beyond the purview of the PDTs. Thus, Science Panel involvement is more critical for large scale monitoring needs.

The current model for large scale monitoring on the UMRS is the Long Term Resource Monitoring Program (LTRMP). The LTRMP monitoring design is focused on collecting data for water quality, fish, and aquatic vegetation in six navigation pools and river reaches and on system-wide acquisition of land cover, bathymetry, and hydrologic data. The LTRMP has, since 1989, developed an extensive and unparalleled ecological database on the UMRS. UMRS natural resource managers should take advantage of the LTRMP database and infrastructure, when appropriate. LTRMP data can be used to help define and quantify objectives, design projects, and to define pre-project conditions. Most previous analyses of LTRMP data have defined means and variability and have analyzed patterns in time and space. The focus of LTRMP has been pool/reach-level monitoring, whereas the NESP intends to expand monitoring for individual projects (table 9). But, the LTRMP may be able to help with monitoring restoration projects implemented in LTRMP focal reaches by increasing sample size in the area of the project. Any new monitoring should build upon existing databases and be managed in ways that allow easy access to both old and new data. In particular, managers should take advantage of the LTRMP database and infrastructure when appropriate.

We expect that within the NESP there will be more need for monitoring than there are resources available. Thus, not all projects can be monitored and the Program must determine what monitoring will be conducted. In general, the highest priority for monitoring should be in situations where we can most effectively learn and achieve Program goals. Reasons not to monitor specific projects include confounding factors that may make it very difficult to detect effects at either local or large scales, thus the potential to learn from the project is low. Also, costs of monitoring may be very high for the information gained, thus monitoring effort can be used more efficiently on other projects. Monitoring is most effective when it can help resolve critical questions about a management action (table 11) or reduce uncertainty in our understanding of how the river system functions. The ability to learn from a project should be one of many considerations in deciding to implement the project, but it should be the primary consideration in determining which projects to monitor. Other reasons to monitor include providing information for multiple projects, helping to develop more efficient monitoring procedures, and providing data for public demonstration projects.

For some management actions and restoration project types we already have fairly good information on local effects and on how to implement them, for example, island construction in St. Paul District and summer drawdowns in St. Louis and St. Paul Districts. These types of projects may require little or no monitoring. For these projects managers need to consider the remaining questions or uncertainties for this technique (table 11), and then determine if the project is appropriate for monitoring relative to these questions.

Table 11. Management actions and restoration project types typically applied to the Upper Mississippi River System. Included are potential objectives and associated monitoring that might apply at local and large scales and some major questions associated each technique [1]

	Local (Area of Direct Effect)		Large Scale (Pool Scale or Larger)		
Project Types And Management Actions	**Objectives (Generally Short-Term)**	**Potential Indicators To Monitor**	**Objectives (Generally Long-Term)**	**Potential Indicators To Monitor**	**Major Questions Or Assumptions**
Construct islands/chevrons Create seed islands Build complete islands	- Modify flows or wind fetch to: Produce wind/current shadow Reduce turbidity Promote plant growth Increase scour along sides - Increase topographic diversity - Increase isolated terrestrial habitat - Provide nest sites - Increase abundance of plants, inverts, backwater fishes and waterfowl	- Abundance & distribution of vegetation and other biota of interest - Bathymetry - Morphometry of created islands - Turbidity & transparency	- Increase habitat diversity - Increase abundance of desirable fish, waterfowl	- Habitat diversity at pool scale or larger - Abundance and diversity of vegetation and other biota at pool scale	- Is habitat limiting abundance of some biota? i.e., do islands increase pool-wide abundance of target biota, or are they most useful for affecting distribution of [or concentrating] biota? - How many are enough?
Backwater restoration Dredge holes or channels within BW's Connect BW to MC Create isolated BW	- Improve habitat features in BW's: oxygen, temperature, current, nutrients - Increase amount of isolated aquatic habitat - Provide overwintering fish habitat - Increase fish access to off-channel areas - Increase abundance of plants/inverts - Increase abundance of backwater fishes and waterfowl	- WQ: D.O., temperature, current, nutrients - Changes in bathymetry or morphometry at project site - Abundance, distribution, or movements of biota of interest	- Increase habitat diversity - Increase abundance of desirable fish, waterfowl	- Habitat diversity at pool scale or larger - Abundance and diversity of vegetation and other biota at pool scale	- Is lack of BW habitat limiting some biota? - What features of BW's are critical and what level of habitat diversity is needed?

Project Types And Management Actions	Local (Area of Direct Effect)		Large Scale (Pool Scale or Larger)		Major Questions Or Assumptions
	Objectives (Generally Short-Term)	**Potential Indicators To Monitor**	**Objectives (Generally Long-Term)**	**Potential Indicators To Monitor**	
Floodplain restoration **Remove/modify levees** **Create/restore wetlands** **Modify land elevations and create specific topography** **Remove/modify drain tile systems** **Cut or plant trees** **Moist soil management**	- Increase connectivity of MC with floodplain and access of biota to floodplain - Modify connectivity and fragmentation of habitats within floodplain - Increase/decrease depth of unsaturated zone - Increase recruitment of desirable trees - Increase diversity in tree community - Increase extent of wetlands and grasslands - Increase topographic & habitat diversity within floodplain - Improve habitat for waterfowl, migrating birds, mammals, reptiles, amphibians - reduce flood elevation locally and downstream	- River stage - Depth of groundwater - Tree recruitment - Species composition of forest - Land cover in project area - Abundance, distribution, or movements of biota of interest	- Increase habitat diversity - Increase diversity in tree community - Increase abundance of desirable biota - reduce economic losses from flooding	- Landcover and species composition in floodplain for landscape/diversity metrics at pool scale or larger - Abundance of vegetation of interest and other biota at pool scale or larger	- Will increased connectivity increase production of aquatic or floodplain biota? - What is the desired pattern of floodplain habitats and successional stages?
Channel Restoration **Modify closing structures or channel inlets/outlets** **Dredging to modify or create new channels** **Notch/modify wing dams** **Increase woody debris** **Recreate rock/riffle areas** **Unchannelize tributary mouths** **Evaluate environmentally friendly training structures**	- Improve habitat features of flowing water areas: oxygen, temperature, current velocity, depth diversity - Modify sediment scour or deposition - Create areas of quiet water (eddies) - Create overwintering fish habitat. - Increase abundance of inverts or fish	- WQ: DO, temperature, current, depth - Sediment scour and deposition - Sediment delivery to the MC - Dredging required in MC - Abundance, distribution, or movements of biota of interest	- Increase habitat diversity - Increase abundance of desirable fish or inverts	- Habitat diversity at pool scale or larger - Abundance of vegetation and other biota at pool scale	- Is fish abundance lower in the navigation channel than in more natural channels? - What features of channels result in greater fish abundance? - How can we restore side channels in the Middle River under the existing hydrologic regime?

Project Types And Management Actions	Local (Area of Direct Effect)		Large Scale (Pool Scale or Larger)		Major Questions Or Assumptions
	Objectives (Generally Short-Term)	**Potential Indicators To Monitor**	**Objectives (Generally Long-Term)**	**Potential Indicators To Monitor**	
Flow modification/re-routing Route flow to BW's Modify closing structures Modify spillways	- Improve habitat: Oxygen, temperature, current, turbidity, nutrients - Modify sediment dynamics - Create holes Scour/deposition - Increase abundance of vegetation, inverts, fish	- WQ: DO, temperature, current,, depth, turbidity, nutrients - Sediment scour/deposition - Bathymetry - Abundance of biota of interest	- Increase habitat diversity - Increase abundance of desirable fish and inverts - Reduce nutrient export from UMRS	- Habitat diversity measures at pool scale or larger - Nutrients measured just above next major nutrient source downstream - Abundance of vegetation and other biota at pool scale	- Are flow-related variables limiting biotic production? - Can we reduce nitrogen by moving it to BW's?
Water Level Management Drawdowns: Individual BW's Pool-wide Dam control point Modify gate operations	- Expose sediments during summer - Dry/aerate/compact sediments - Increase abundance of emergent plants - Increase area of photic zone -Increase abundance of submersed & floating-leaved aquatic plants - Increase denitrification - Reduce elevation of water table - Increase recruitment of desirable trees - Reduce short-term variation in water levels - Pulse water into BW's to improve water quality (DO, nutrients)	- Elevation of surface and ground waters - Nutrient input/output for project area. -WQ: DO, turbidity, nutrients - Abundance/distribution of aquatic vegetation - Recruitment of forest trees	- Restore more natural hydrograph - Increase abundance of aquatic plants - Modify relative abundance of forest trees - Increase abundance of desirable fish, waterfowl, shorebirds, terrestrial vegetation	- Index of Hydrologic Alteration - Abundance & distribution of aquatic & terrestrial vegetation and other biota at pool scale	- Does a more natural hydrograph affect biotic production? - Can we increase abundance of aquatic vegetation with drawdowns? How long does the effect last? - How long does deep dredging last? - Can drawdowns effect forest species composition? - Does water level manipulation (drawdowns, control point, short term variation) increase long-term abundance of aquatic fauna?
Improve Fish Passage Modify gate/lock operations Construct fishways	- Increase number of fish moving upstream past dam	- Number of fish moving past a dam (species of interest) - Abundance of fish in upstream pools and tributaries	- Increase abundance of desirable fish	- Abundance of fish species of interest within the affected reach of the river or system wide.	- How much "passage" is needed to support target levels of abundance or diversity within different reaches of the system?
Control invasive species Direct control techniques Habitat modification	- Reduce abundance or distribution of invasive species	- Abundance of invasives in project area (absolute or relative)	- Reduce abundance or distribution of invasive species	- Abundance and distribution of invasive species at reach or system scale.	- How can we keep new invasives out of the system? - How can we reduce negative ecological effect of existing exotic species?

Project Types And Management Actions	Local (Area of Direct Effect) Objectives (Generally Short-Term)	Local (Area of Direct Effect) Potential Indicators To Monitor	Large Scale (Pool Scale or Larger) Objectives (Generally Long-Term)	Large Scale (Pool Scale or Larger) Potential Indicators To Monitor	Major Questions Or Assumptions
Sediment Management Shoreline stabilization Sediment traps at tributary confluences Dredging	- Reduce sediment input from tributaries - Reduce erosion of shorelines - Maintain channel depth - Reduce infilling of channels and BW's	- Sediment loads (suspended & bed load) - Mapping of channels & shorelines - Amount of dredging required in MC - Sediment scour and deposition - Sediment delivery to the MC	- Maintain deep aquatic habitats & habitat diversity - Reduce dredging needs - Increase abundance of desirable fishes & fish diversity	- Bathymetry in channels & BW's - Dredging records - Abundance of fish species of interest & fish diversity	- Can we modify sediment dynamics in ecologically meaningful ways? - Can we reduce sediment input from tributaries by modifying tributary mouths or by changing practices on uplands?
Regulations & Access [2] Controls on shipping season or timing Regulations on fleeting areas Barge draft regulations Build more boat ramps	- Reduce local effects of navigation operations - Increase recreational access for trailered boats.	- Recreational use surveys - Changes in local abundance or distribution of biota	- Increase recreational access - Increase abundance of desirable fish, waterfowl, shorebirds, terrestrial vegetation - increase efficiency of commodity transport	- Recreational use surveys - Abundance of biota of interest	- Does recreational boating decrease abundance of biota? - Does more water under the keel reduce negative effects of barge traffic?
General features of all techniques			- Water quality at fishable & swimmable levels - Maintain commercial navigation - Maintain or increase recreational access - Reduce losses from flooding		- If we rebuild the habitat mosaic that existed after initial impoundment): - will abundance of desirable biota increase? - will river processes be restored (i.e., does function follow form)? -will this work only if other basic processes are still intact (e.g., flow regime, river bed & floodplain elevation, few exotic species, etc.) - Is habitat diversity directly related to biotic diversity and river health?

[1] MC = main channel; BW = backwaters; WQ = water quality

[2] There are many types of regulations on human activities that may affect UMRS ecosystem objectives, but that are not under NESP control. Examples include fishing and hunting regulations, designating areas as closed or limited access, no-wake regulations, regulations on discharges and pollutants, and changes in land use or agricultural operations on uplands.

G. Monitoring to Evaluate Success in Achieving Goals and Objectives

Projects undertaken for UMRS ecosystem restoration will incorporate a variety of management actions (table 11) including construction efforts that modify the physical nature of the river and modifications to operation of the navigation system. NESP projects will be objective-based with predicted outcomes that must be detectable by monitoring. Monitoring should assess how well projects achieve their local objectives and contribute to achieving larger-scale goals.

1. Local Effects of Individual Projects

Project performance monitoring is the evaluation of the local, site-specific effects of a project. Evaluations at local scales can determine whether a project was implemented as designed, whether it achieved its local objectives, the spatial extent of project effects, and provide feedback on technical aspects to help improve future project design and implementation. Potential questions to address could include, did construction match the planned design, is water flowing where intended, did the planted vegetation survive, how much vegetation grew on exposed substrates, or how many fish use a passage structure? Some local effects may take longer to evaluate, such as, how long will an island or dredge cut last, did the fish population increase, or how long did increased vegetation abundance persist? There can be many site-specific objectives, thus the list of local effects could be quite long and include both ecological and engineering issues.

The PDTs will identify objectives for each project. Associated with each objective are indicators that, when measured over time, can provide monitoring data that allows assessment of the degree to which the objectives are attained (see Objectives chapter above). The PDTs will design monitoring plans for individual projects around the primary project objectives and associated indicators.

The Science Panel is charged with helping PDTs to develop monitoring plans. The Science Panel will provide general guidance for the kinds of monitoring that should be considered under each type of project and management action (table 10). Specific plans should be developed by the PDTs with input from the Science Panel as needed. For each project, the PDT should recommend specific variables (indicators) to be evaluated at both local and large scales and the procedures needed for monitoring those variables. These plans should consider the anticipated trajectory of project effects over time (figure 11) and include the expected time frame for monitoring for each indicator. Some indicators are likely to exhibit time lags or transition periods. If it is not necessary to know the response trajectory of these effects over time, then annual monitoring may be "overkill" and it may be most efficient to delay monitoring until the effect in question is fully realized. Elements to be considered in monitoring designs could include project objectives, variability, effect size, expected geographic area of effects, pre-project and post-project monitoring, time frame (number of years, lag times for responses), control sites, opportunities to combine with other monitoring efforts, and methods for data analyses. Monitoring plans should consider that some initial effects may be negative, but short-lived, with positive effects seen over a longer time frame. A possible example is loss of unionid mussels in shallow areas during an initial drawdown (figure 11). Ideally, negative effects identified for specific project types can be countered through changes in design or implementation.

Fig __.

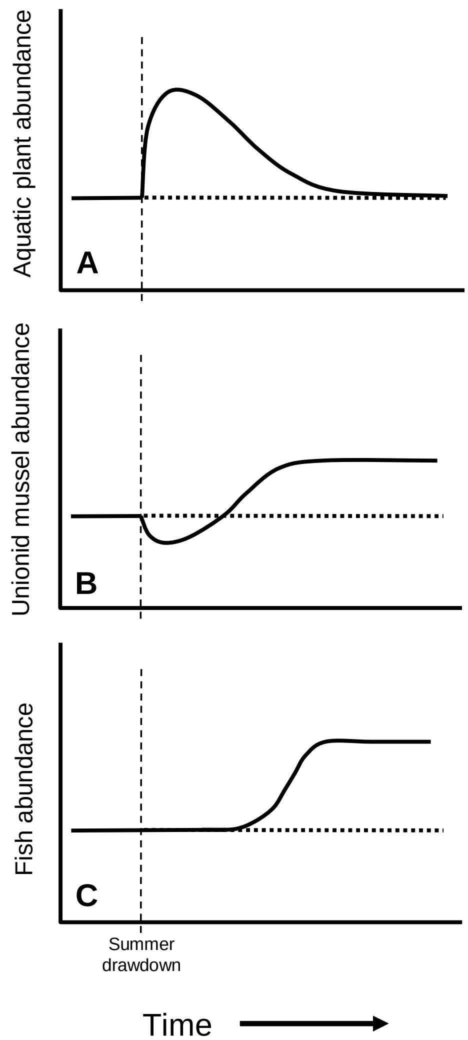

Figure 10. Hypothetical trajectories for abundance of (A) aquatic plants, (B) unionid mussels, and (C) fish in the years following a summer drawdown. A rapid increase in aquatic plant abundance is expected (A) followed by an eventual decrease and return to pre-drawdown levels. Unionid mussel abundance may decrease initially (B) because some mussels are stranded in exposed areas and die. However, if drawdowns contribute to fish abundance and concentrate fish hosts over mussel beds, mussel reproduction may increase leading to increased abundance over time. Increased plants may also increase fish reproduction, but if monitoring samples adult fish, there will be a lag before that indicator shows a response (C).

The monitoring plan should try to maximize the efficiency of conducting field work. Recommendations from the PDT will be reviewed by the NESP program managers and the Science Panel to ensure that local objectives are evaluated effectively. As indicated previously, not all projects will require extensive monitoring. If a project is not likely to be monitored, there is no need to develop an extensive monitoring plan. The Science Panel, Corps, and River Teams should develop a process for evaluating proposed projects to determine which ones should have full scale monitoring plans developed (see Project Evaluation and Sequencing of Proposed Restoration Projects above).

Most project monitoring plans will require pre-project data. However, for most projects, pre-data will be lacking so monitoring plans will need to include collection of pre-project data. The exceptions may be for projects in the LTRMP focal reaches. However, the LTRMP is designed to provide data at the pool and strata scales, thus LTRMP data may not provide sufficient coverage to estimate conditions at specific project locations.

The Science Panel and PDTs should discuss protocols for data collection in areas with little pre-project data. Some rapid assessment protocols have been developed or streams that might be adaptable to large rivers. In addition, the U.S. Environmental Protections Agency's Great Rivers Environmental Monitoring and Assessment Program (http://www.epa.gov/emap/greatriver/) is currently sampling on the Upper Mississippi, Ohio, and Missouri Rivers to develop and test procedures for assessing river health. An underlying question for river managers is whether an assessment of generalized indicators in a new area is useful or whether we should sample only for specific indicators in new areas? In addition, how can we assess natural variability for an indicator in a short period of time?

2. Multiple Projects and Cumulative Effects

Multiple ecosystem restoration projects may be related in three main ways: (1) projects of the same type in the one reach, (2) projects of the same type in different reaches, and (3) projects of different types in one reach. These multiple projects present opportunities for different experimental designs that can address how to combine and integrate projects to achieve greater results.

Multiple projects of one type within one reach can help address the question of, "How much is enough?" From multiple projects, we can develop response curves showing incremental benefits gained as the number of projects increase. These curves can help indicate: how many projects are needed to elicit an initial response; if there are diminishing returns from multiple projects; and the maximum response expected from multiple projects within a reach. An opportunity to address this question relative to island building exists in Pool 8 using LTRMP data as more island projects are constructed. Addressing these cumulative effects requires monitoring at the reach scale.

Multiple projects of one type in different reaches can help address issues related to project design and implementation. A single management action applied at multiple locations can provide data on differences in responses under different conditions. For example, similar projects raising floodplain elevation to allow growth of flood-intolerant trees could be implemented in different reaches in a factorial design (4 sites/reach x 2 relative elevations x 2 reaches) examining the effects of stage duration and the vegetation response could be monitored. Similar designs might apply to fish passage, levee removal, or drawdowns.

The third category of multiple projects - projects of different types within one reach – will probably be the most common approach to rehabilitation. This approach is evident in the pool plans developed for Pools 2 – 10, and in the pool and reach planning approach being conducted for the NESP. Monitoring in these reaches may involve a combination of evaluation of local effects for individual projects along with larger scale monitoring to detect reach-wide effects. However, singling out the effect of one project or management action may be difficult because the effects of multiple projects are likely to be statistically confounded. For example, separating the effects of island construction in Pool 8 from the drawdown conducted in 2001-2002. This approach presents many challenges in experimental design and statistical analyses. In some cases, we may only be able to define the combined effect of multiple projects. However, this is the only approach that can address questions of synergy among projects (That is, are some projects more effective in combination with other measures?) or sequencing of projects (Should some projects be conducted before others?).

Evaluations of multiple projects can take two different approaches. First is evaluations that are developed when a series or combination of projects are initially planned. In this approach, the initial planning for the projects will include consideration of multi-project design, monitoring, and data analyses. The second approach is to design evaluations after a series of projects is completed. This approach may propose new post-project monitoring, or may use existing data collected by others. The first approach should be more efficient and effective than the second, after-the-fact approach, and PDTs should use the first approach when possible. However, after-the-fact evaluations through analyses of existing data are generally low cost, although they may not provide the statistical rigor desired because the data available were not designed for the question at hand. UMRS stakeholders should consider how this approach can be used now with existing LTRMP and Environmental Management Program project data to address critical questions and develop hypotheses that can be tested through new projects or experiments.

Determining the effects of multiple projects, using either evaluation approach, is complex and will require careful consideration of project designs, implementation sequences, monitoring plans, and analytical techniques. Only by careful selection of projects, data, and analyses can we hope to identify, separate, and quantify the specific effects we are interested in proposals for multi-project evaluations can be developed by the PDTs, River Teams, or Science Panel. The Science Panel should be closely involved in development of these plans to ensure that designs and analyses are scientifically and statistically appropriate.

3. Pool and Reach Scale Monitoring

Achieving systemic rehabilitation will require success within the many different reaches and pools of the UMRS (figure 5). Reach-scale effects may not be expected for small, individual projects, but would be expected from multiple projects within a reach and from large-scale projects such as pool-wide drawdowns, change of control point, fish passage, or extensive rehabilitation of floodplains or side channels. For large-scale projects, a reach may be the most appropriate spatial scale for monitoring and pre- and post-monitoring plans will be required for the specific reach where the project is implemented.

For multiple projects, it may be more efficient to concentrate projects in specific reaches where we have a historical database and we expect to continue reach scale monitoring. Currently, those reaches are the six LTRMP focal reaches. For projects in those reaches, the LTRMP database can provide baseline information and continued sampling will provide estimates of reach-wide indicators as each new project is implemented. However, reach-scale monitoring will not replace monitoring for local effects because the sampling levels required to estimate reach scale indicators are generally too coarse to provide adequate sample sizes for estimating local effects. But it may be possible to leverage the reach scale monitoring effort and have sampling crews collect extra samples within the expected area of influence for a small-scale project. These extra samples would not be used to generate reach wide estimates, but could be an efficient way to use the existing infrastructure to collect data on local effects. In the same vein, we may be able to use reach-scale sampling to investigate the spatial extent of effects for small scale projects.

Although implementing multiple projects in a single reach has many benefits, it also presents the risk of confounding the effects among projects. If we are interested in isolating a specific effect for a management action, we may need to implement those projects in separate areas where their effects are independent of other projects.

Over time, the Long Term Resource Monitoring Program focal reaches should provide considerable information to advance our knowledge base on the success of different rehabilitation techniques and multiple projects. As our knowledge of, and experience with, different management actions increases, we expect that managers can apply them in other locations within the same region and see similar responses. Thus, the need for monitoring can be reduced or redirected to new questions and issues.

The Science Panel should provide leadership to develop and coordinate monitoring plans that address multiple projects within a single river reach or pool. One potential approach is to maintain at least one focal pool or reach in each of the four floodplain reaches of the UMRS, and to concentrate projects and monitoring in those focal reaches, although this would probably be unacceptable to the River Teams and stakeholders. Sampling within each focal reach would cover a broad suite of components (similar to LTRMP sampling now) to estimate reach-wide effects and produce a broad database that acts as a baseline for evaluating effects of new projects. The most likely candidates for focal reaches are the current LTRMP reaches. Projects could be implemented in other reaches based on rehabilitation needs and could be monitored as appropriate, based on their ability to provide valuable data or learning. Adding a second focal reach in some or all regions would offer some advantages. Two focal reaches would provide some replication for project types within a single floodplain reach and improve the ability to draw inferences about project effects. The primary drawbacks would be increased expense and concentrated restoration effort in selected areas.

The Science Panel should work with the UMRS stakeholders to address critical questions regarding reach scale monitoring, including:

- Is it worthwhile to begin reach-wide monitoring in new areas or should we concentrate on individual research and monitoring efforts in areas that are not current LTRMP focal reaches?
- Are there rapid assessment protocols or reduced monitoring designs that can be applied to new areas at lower cost and effort?
- Can we develop complimentary designs for monitoring that serve both project-specific and reach-wide needs?

4. Regional and Systemic Monitoring

The vision for the UMRS is "To seek long-term sustainability of the economic uses and ecological integrity of the Upper Mississippi River System." Thus we need some way to evaluate success at achieving this systemic goal. System level responses cannot be determined through local project evaluations. Monitoring at the system scale may be confounded by large-scale changes in the system and its underlying drivers (e.g., climate, watershed modifications) over time. In addition, different changes may occur in different parts of the system such that the benefits of restoration in one location may be counteracted by degradation at another location, thus showing no overall benefit at large scales. Some of this variability may be accounted for by monitoring designs that allow considering the four major floodplain reaches of the UMRS separately.

There is a wide range of options for evaluating success in achieving systemic goals. We discuss three possibilities here. The first option is to conduct no systemic monitoring, but to assume that the effects seen from evaluations of individual and multiple projects in focal reaches will be additive and will result in systemic level improvements as more projects are implemented. This is essentially the model used under the current LTRMP, where the focal reaches are assumed to represent conditions within their floodplain reach. This approach requires the least effort, but does not provide any empirical estimate of indicators at the system level. Thus, if the assumption of additive effects is wrong, we run the risk of achieving considerable success with local projects, but not achieving systemic goals. An example might be the Columbia River system, where many small-scale projects have succeeded in getting salmon past dams, but most salmon populations have still not recovered.

A second approach is to monitor two pools per floodplain reach: one focal pool in which we implement a variety of projects, and one reach in which we implement no, or very few, projects. The second reach would be used as a control to compare to the focal reach. If conditions in the focal reach improve relative to the control reach, we assume that systemic rehabilitation will be achieved when we implement similar projects in non-focal reaches. While this approach provides some estimate of reach-level conditions without rehabilitation, it is really only a comparison between the two selected reaches. It does not produce any estimate of conditions in other reaches and cannot test the assumption that systemic rehabilitation will succeed. In addition, the control reach may not be truly independent of other reaches. If rehabilitation in other reaches produces improvements that “spill over” into the control reach, then the control reach becomes a moving target for rehabilitation and the true level of success remains unknown.

A third approach is to conduct annual monitoring in non-focal reaches that are randomly selected within each of the four floodplain reaches. These reaches will exhibit various levels of project implementation and rehabilitation. Sampling in these reaches could be designed mainly to detect trends and could be conducted at a lower level of intensity than in focal reaches. The design could provide an annual estimate of conditions within a floodplain reach and data could be combined among floodplain reaches to calculate systemic indicators, when appropriate. The design would allow for comparing indicators over time within a reach, or comparing to focal reaches. In addition, as specific reaches are sampled multiple times, estimates of conditions within each reach over time would be possible. Of the three approaches outlined here, this is the only one that could provide unbiased estimates of indicators on a regional or systemic level. This approach would probably involve more travel and logistic considerations than the other approaches and thus, be more expensive. But, the total amount of effort needed would depend on a variety of factors that would require considerable discussion within NESP.

At the region and system scales, there is considerable infrastructure and historical data to draw on for developing an ecosystem monitoring structure. As with the reach scale, the LTRMP provides the most extensive framework to build from, but modifications to the LTRMP approach may be needed to achieve specific objectives within the NESP. Such modifications could involve spatial coverage, temporal frame, or the types of data collected. Any modifications should try to ensure continuity with existing data from LTRMP focal areas. A systemic monitoring plan developed by the Science Panel should consider questions such as:

1. Should we maintain or expand the LTRMP design of 6 focal pools?
2. Should we expand the habitats included within LTRMP (e.g., floodplain, main channel)?
3. How can system-level monitoring contribute to, or coordinate with, monitoring at the reach and local scales?
4. Should NESP concentrate projects in LTRMP pools?
5. Should we expand the indicators currently measured by LTRMP to include ecological processes, ecosystem services, or socioeconomic indicators?
6. Do LTRMP designs and procedures measure the variables needed to evaluate success in achieving UMRS goals and objectives?

We may also want to consider new approaches for collecting some types of information. A modified monitoring approach may be appropriate for some water quality variables, especially for constituents like nutrients and sediments for which we are interested in reach level estimates of budgets, loads, and amount exported, not just averages or dynamics within the reach. For these constituents, sampling at input locations (i.e., upstream end of the reach and at the confluence of major tributaries) and at the output of the reach may be critical, with temporal dynamics addressed through flow-weighted sampling. In addition, NESP should consider programs other than LTRMP that might provide data for monitoring or special analyses. This could include such long-term programs as the U.S. Geological Survey's National Stream Quality Accounting Network (NASQAN, http://water.usgs.gov/nasqan/) and National Water Quality Assessment Program (NAWQA, http://water.usgs.gov/nawqa/), and the Long Term Illinois River Fish Population Monitoring Program conducted by the Illinois Natural History Survey (http://www.inhs.uiuc.edu/cae/ltrm/ltef.html). Also, the Environmental Protection Agency's Regional Environmental Monitoring and Assessment Program (REMAP, http://www.epa.gov/emap/remap/) and Great Rivers EMAP (http://www.epa.gov/emap/greatriver/) have collected data to assess environmental health of the Upper Mississippi, Ohio, and Missouri Rivers and some of their major tributaries. These EMAP programs do not conduct long term monitoring, but are in the process of developing a spatially-extensive, multidisciplinary database on these rivers from 2004 through 2007.

The Science Panel, in cooperation with the UMRS managers, should develop a system-scale monitoring plan for review by the River Council.

H. Monitoring for Reporting Status of the System

In addition to monitoring projects, the NESP will need information to develop a Report Card for the UMRS ecosystem. The Report Card is meant to track success at rehabilitating the ecosystem using simple indicators that can be readily understood by the public. The Report Card concentrates mainly on reach and system scales rather than on individual projects, but the data may be accessible at a variety of scales, as applicable, through the decision support system. Indicators that can synthesize information across ecosystem components will also be selected, where possible. The monitoring team will assure the technical integrity of indicator measurements and analysis. The monitoring and modeling team will coordinate to synthesize data into useful ecosystem scale results for reporting. Reporting parameters may change as we learn more about our ability to understand, measure, and value specific ecosystem services. Ensuring that monitoring efforts capture the information needed will require coordination between the Science Panel Monitoring and Report Card Teams.

I. Monitoring as a Learning Tool Within Adaptive Management

The third type of data required from monitoring is data to increase our understanding of how the river functions. This will occur mainly through data analyses and modeling, which should improve our ability to predict the effects of management actions. Monitoring designs should consider data needed to conduct critical analyses, to estimate model relations or parameters, to calibrate models, and to evaluate model predictions. Data needed for modeling can come from monitoring or from focused field studies, laboratory experiments, or comparisons among different locations within the system, and can involve both ecological and engineering questions. The most useful learning experiences will be those that can test hypotheses about the effects of different project designs and management actions.

The primary approach to learning about UMRS ecosystem restoration will be adaptive management. Modeling plays a critical role in adaptive management, and monitoring supplies the basic data needed to inform the modeling process and to assess modeling predictions. Conversely, modeling can contribute to monitoring in a variety of ways including helping to determine which uncertainties are most important to address, what indicators are likely to be most informative, and the most effective timing for monitoring critical indicators.

In addition, any monitoring program should apply adaptive management to its own operations and always be looking for new and more efficient ways to collect monitoring data. Any changes to monitoring procedures should consider the continuity of data and of inferences derived from those data. Changes that increase efficiency with no loss of data should be welcome, but any change that affects data quantity, quality, or analyses should be carefully weighed. Given the large spatial and temporal scales evident in large river monitoring and the high cost associated with hands-on monitoring at those scales, the role of remote sensing should be explored as new instruments, techniques, and procedures become available.

J. The Future Role of the Science Panel in Monitoring

In the initial phases of the NESP the Science Panel will be closely involved in determining the critical questions to be addressed by monitoring, developing analyses that can be conducted to inform future monitoring, helping PDTs develop monitoring plans, and advising the partnership on development of reach and system-level monitoring plans. The Science Panel will have a continuing role in monitoring by helping develop and review monitoring plans for individual and multiple projects, advising on analyses of monitoring data, and advising the River Council and Corps on design and sampling issues associated with reach and system-scale monitoring, including modifications for efficiency. A critical first step for the Science Panel will be to develop an effective method for ongoing interaction with PDTs and River Teams.

In general, the Science Panel, working in conjunction with the PDTs and River Teams, should recommend how total monitoring effort can be used most effectively, considering the learning potential for individual and multiple projects and the need for evaluating success in achieving long term program goals.

7 Modeling

A. Area of Responsibility

The Modeling and Integration Workgroup (Workgroup) of the Science Panel provides guidance on model selection, integration methods, and applications in collaboration with all Science Panel members and Corps planners with responsibilities under the NESP. Models play an important part in restoration planning and ecosystem management. Integrated physical process and ecological models should also play an important role in the development and implementation of any adaptive ecosystem management plan. Models can be used to: (1) forecast and help understand the likely outcomes of specific restoration and management actions as previously suggested; (2) assist in the design of monitoring programs for adaptive management; (3) provide estimates of variability and uncertainty to plan robust sampling designs; and (4) better understand risks associated with unanticipated results of restoration actions. The workgroup was charged with developing a conceptual framework and recommendations that outline the potential contributions of modeling to the UMRS adaptive management program.

B. Members

A subgroup of the panel formed the Modeling, Integration, and Application Workgroup. The workgroup is comprised of the following members:

Science Panel
John Nestler – USACE, ERDC, Waterways Experiment Station, Vicksburg, Mississippi
Steve Bartell – E2 Consulting Engineers, Inc, Maryville, Tennessee
Charlie Berger – USACE, ERDC, Waterways Experiment Station, Vicksburg, Mississippi
Barry Johnson – USGS, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin
Larry Weber – University of Iowa, Iowa City, Iowa

Support Team
Robert Davinroy – USACE, St. Louis District, St. Louis, Missouri
John Hendrickson – USACE, St. Paul District, St. Paul, Minnesota
Kevin Landwehr – USACE, Rock Island District, Rock Island, Illinois
Charles Theiling – USACE, Rock Island District, Rock Island, Illinois
Daniel Wilcox – USACE, St. Paul District, St. Paul, Minnesota

C. Objectives

The role of the Panel's Modeling Team is to: 1) develop a conceptual framework to describe modeling support the NESP; 2) emphasize overarching UMRS ecosystem goals and objectives that can be served by modeling; 3) refine existing models to specific management actions; 4) help forecast outcomes of specific management actions; 5) integrate modeling into UMRS adaptive management; 6) help design a meaningful ecological report card that includes endpoints or performance measures that can be measured and modeled; and 7) provide other modeling-related support, review, and guidance as requested.

D. Approach

The Modeling Team's primary responsibility was to develop a conceptual framework that outlines the potential contributions of modeling to support adaptive ecosystem management in relation to the NESP. The diversity of potential model applications required a broad range of modeling capabilities to be represented in the group. Hydraulic, sediment transport, and ecological modelers described and exchanged experiences with computer and laboratory simulations and prototype implementations. They also discussed state-of-the-art applications that are highly integrated and dynamic. They considered forecasting models, risk assessment models, and performance assessment modeling needs.

The Modeling Team also addressed its role and the potential contributions of integrated physical and ecological models within the broader context of environmental sustainability. Integrated models might be used to help design individual projects or combinations of projects in a way that contributes to sustainability at the local, reach, or system scale. Models might be used to define relevant performance measures or project design criteria that can be monitored and evaluated in relation to UMRS ecosystem goals and objectives consistent with larger-scale sustainability.

The Modeling Team convened a workshop at the University of Iowa's Mississippi Riverside Environmental Research Station, Muscatine, Iowa, from 28-30 June 2005. The theme of the workshop was to "Create a collegial setting for free and open exchange of ideas to develop a consensus strategy for building tools to guide restoration planning, archive information, and institutionalize learning about ecosystem response to management action and propose applications within the UMRS." In addition to members of the Workgroup, listed above, the workshop was also attended by:

John Barko, Jean O'Neil, Steve Ashby – USACE, ERDC, Waterways Experiment Station, Vicksburg, Mississippi

Ken Barr, Sandra Brewer – USACE, Rock Island District, Rock Island, Illinois

Thomas Keevin, John Cannon – USACE, St. Louis District, St. Louis, Missouri

Michael Davis – Minnesota Department of Natural Resources, Lake City, Minnesota

Andy McCoy, Nate Young – Iowa Institute of Hydraulic Research, University of Iowa, Iowa City, Iowa

Karen Westphall, U.S. Fish and Wildlife Service, Mark Twain Refuge, Quincy, Illinois

Robert Clevenstine – U.S. Fish and Wildlife Service, Ecological Services, Rock Island, Illinois

E. Integration Plan

Integration occurs at four levels within the activities of the Science Panel: (1) integration of science into decision-making, (2) integration of skills and experience across the different workgroups, (3) integration of individual restoration projects into larger-scale system restoration, and (4) integration of separate modeling tools and approaches relevant to the UMRS into a system-level modeling and assessment capability. Modeling activities are viewed as central in the integration of other Science Panel work groups, therefore, a Modeling Team member is usually represented on each of the other work groups. One member of each of the other Panel workgroups also participated in the

Modeling Workshop to provide the diversity of viewpoints necessary to insure adequate integration across Science Panel teams. Models used in support of UMRS adaptive management may be developed and applied in other Panel workgroups, but these models will be integrated through this work group.

F. Results

1. Conceptual Framework

The UMR-IWW System Navigation Feasibility Study Environmental Science Panel (Lubinski and Barko 2003) reported that "Models can and should be used to develop concepts, simulate processes, refine hypotheses, forecast future conditions, conduct planning, assess the results of monitoring, identify additional information needs, and inform stakeholders." Workshop participants consistently emphasized the need for a comprehensive system of tools that incorporates a family of ecosystem models assembled to address the stated Panel needs. For a single project this family of models could be used to develop objectives, identify alternative management actions, forecast outcomes of alternative management actions, guide design monitoring plans, assess progress towards objectives, forecast outputs of ecosystem services, and serve as a repository of lessons learned as models are updated with new information. At the program level, models can be used to track program progress by integrating progress toward attaining river reach and system-wide objectives, summarizing changes in ecosystem outputs, and by estimating their value to society. Most importantly, these tools must be developed in a scientifically and technically defensible manner in order that it will be trusted and used by the community of UMRS river managers and scientists.

The Modeling Team recognized the conceptual and technical interrelationships between modeling and monitoring in support of the NESP. However, the group also understood that monitoring should not be performed solely to serve modeling. Both modeling and monitoring should be performed within the framework provided by the UMRS conceptual model (Lubinski and Barko 2003). Following this approach can help increase the likelihood that monitoring programs will provide results that can be used to both assess project status and trends, as well as evaluate model forecasts. Using the conceptual model to guide monitoring and modeling might also facilitate interactions among the NESP, stakeholders, and the interested public.

Issues of scale are important with large ecosystem management and restoration projects such as the NESP. Models of different ecological complexity (resolution) should be developed commensurately for local, reach, and system-wide scales. The Modeling Team recommended that two differently-scaled approaches should be implemented:

- **Approach I** entails the development and application of comparatively complex (e.g., process-level) models to specific projects. Modeled projects can be selected in part based on the opportunity to rapidly and efficiently evaluate model performance. Approach I will also provide for the simplification of highly complex models, for example, through the derivation of empirical relationships between outputs of the complex models and important input variables, including river elevation or discharge.

- **Approach II** builds on the previous approach by incorporating the simplified models into an operational framework that forecasts larger-scale responses, including reach-level and system-wide scales.

2. Incorporating Environmental Objectives

Environmental objectives are central to the adaptive ecosystem management approach of the NESP, and it is strongly believed that modeling is important in understanding the system and integrating complex ecosystem processes. The Modeling Team incorporated UMRS ecosystem objectives into the modeling framework by linking specific ecological models with each environmental objective (table 2). For ease of use, information about models is separated into three categories discussed below: conceptual models, ecosystem models, and detailed models of specific ecosystem components. Each model in the table is also briefly described and referenced in Appendix C. To avoid duplication of effort and to make maximum use of existing tools workshop participants presented summaries of modeling tools and approaches with which they were familiar. While the review was not exhaustive, a number of useful tools and approaches were identified.

Models can help answer difficult questions such as how many projects and at what scales of individual projects are needed to achieve responses that are representative of UMRS environmental goals and objectives and that measurable at a project, pool or reach level. Integrating many of the ecological and physical models listed can contribute towards linking scales by extrapolating project scale effects to larger scales Integrated models can also be used in a predictive capacity to forecast and evaluate responses across temporal scales.

Physico-chemical models are inherently different than biological models. The output of these two categories of models must be integrated before modeling can achieve its full utility for decision support. Physico-chemical and ecological models can be integrated either with or without feedbacks. If feedbacks can be ignored, then the outputs of physico-chemical models (e.g., hydrologic, hydraulic, sediment transport, and water quality) can drive the ecological models under the assumption that the models are independent. Where feedbacks cannot be ignored, then changing ecological conditions must feedback into the physico-chemical models. For example, in some cases, increased biomass of submerged aquatic vegetation might affect hydraulic conditions so that the hydraulic and plant growth models must be dynamically coupled and solved simultaneously.

3. Assessment of Existing Environmental Models

The term *environmental model* is broadly defined to include all models that would be useful to UMRS ecosystem restoration decision support. The general categories of models considered were: conceptual; water quality; hydrologic; hydraulic; geomorphic; habitat; species; and community.

As a group, these models could be used for tasks that include: simulation for scientific understanding, forecasting effects and benefits for alternatives analysis, systematic project evaluation, standardized visualization of effects, a framework for data integration, risk assessment, and as the repository of learning acquired during adaptive management.

Some of these existing modeling capabilities are summarized in the following sections which align, roughly, with UMRS Essential Ecosystem Characteristics (EECs). The discussion is very general because specific modeling activities can become quickly detailed and complicated.

The best model of any system is itself. Therefore, analysis of existing data should be employed whenever possible. For example, data from existing project level studies or surveys could be evaluated to determine best procedures to integrate benefits and effects progressively from pool, to reach, and to system scales.

a. Conceptual Models. Use of conceptual models needs to become a fundamental component of UMRS ecosystem management and restoration planning and administration to help PDTs visualize problems, processes, management actions, outcomes, and even evaluation feedback loops. The early planning stages for all projects of any scale should include conceptual model development. Program managers can use the model structure to track project and program progress and performance. Scientists can use the tool to study complex ecosystem processes that they then test in the field. A well designed conceptual model can also be an effective public communication tool.

Conceptual model automation should be part of the decision support system. The UMR-IWW System Navigation Feasibility Study Science Panel developed a conceptual model for adaptive management with specific applications for water level management and island building (Lubinski and Barko 2003). This conceptual model can be used to guide development of future conceptual models for UMRS ecosystem management. Members of the Modeling Team will be available to help integrate and refine conceptual models with planning and management teams.

Conceptual modeling has a documented benefit in significant national restoration activities. For example, conceptual modeling activities in the Chesapeake Bay, Delaware River, and the Comprehensive Everglades Restoration Plan were highlighted during a review of conceptual modeling activities in other systems. The South Florida modeling process (Harwell et al.1999) which consider scientific and social objectives were captured during the first Science Panel and still form the basis of the current approach. The modeling work in Delaware (Reiter 2004) introduced an interesting probability analysis of the likelihood of management actions to achieve desired objectives using fuzzy logic and Monte Carlo simulation. The application of this tool may be helpful in sorting the many integrated objectives on the UMRS.

The Modeling Team can help integrate and refine conceptual models with planning and management teams. It is important that the Modeling Team emphasizes conceptual modeling during the early planning stages of all projects. UMRS conceptual model automation should be incorporated into the decision support system.

b. Water Quality Models. Many management and restoration projects will affect water quality. In addition, water quality is linked to aquatic habitat by complicated feedback loops that can be positive or negative. For example, improved water clarity and increased dissolved oxygen are important objectives affected by the placement of structures or manipulation of water levels. These actions also promote aquatic plants which, in turn, affect nutrient availability.

A number of water quality models are available for use in the UMRS, particularly for temperature and dissolved oxygen prediction. Several models address nutrient dynamics in aquatic systems. Water quality models have been implemented for Navigation Pools 2, 3, and 4 to examine the relative contributions of point and nonpoint sources of phosphorus to P dynamics in the upper river. The CASM also simulates the effects of nutrient enrichment (N, P) on algal production, models dissolved oxygen, and estimates ecological risks posed by chemical contaminants in complex aquatic food webs (Bartell 2003, Bartell et al. 2000, 1999). CE-QUAL-ICM, normally used in estuarine settings, has the potential to simulate important shallow water processes such as SAV growth and sediment diagenesis. Hydraulic models can be used to understand how suspended sediment dynamics can affect water clarity, which is a strong water quality driving factor in UMRS aquatic habitats. The Modeling Team will help match capabilities of individual water quality models with the modeling support needs of selected management and restoration actions in the UMRS.

c. Geomorphology Models . Geomorphology mathematical models available for the UMRS are limited compared to models that simulate other resource categories, although, the sediment transport features of several of the H&H models (e.g., SED2D, CCHE2D) might provide insights into within-pool changes in geomorphology for individual projects. Physical bed modeling is another tool that has had wide application in the Unimpounded Reach and several pooled reaches. Micro-models developed in the St. Louis District are frequently used to brainstorm restoration opportunities with stakeholders. The models allow stakeholders to experiment with structure design and placement and watch as bedforms shift in response.

Alternatives that appear to produce habitat benefits without impeding the channel can then be designed with greater precision and surveyed for bedform response. The Micro-model results have proven to be extremely accurate compared to prototype (i.e., the river) response. The ability to simulate complex fluvial processes like delta and island formation, sediment deposition on the floodplain, or change in geometry of the channels and floodplains in relation to restoration activities appears largely absent, especially at larger scales.

The Modeling Team should conduct a search of the geomorphology modeling literature to determine if the needed modeling capabilities have been developed elsewhere. If such searches prove unsuccessful, the Team will guide the design and development of the necessary geomorphology models to support ecosystem restoration planning. High resolution topographic data and a refined geomorphic feature classification system should also be pursued to aid geomorphic modeling activities.

d. Hydrology & Hydraulic Models. There was general consensus at the workshop that the existing hydrology & hydraulic models are proven technologies that have direct relevance to the UMRS ecosystem management and restoration (Appendix C). Several of these models, particularly RMA-2, have been applied to characterize the hydrodynamics in selected navigation pools in the UMRS (e.g., Pool 8, Pool 5) as part of the UMR-IWW Navigation Study. The various capabilities of these 1- , 2-, and 3-dimensional models suggest that the hydrology & hydraulic models can be usefully applied to examine localized to pool-scale changes in flows and water elevations that result from individual projects. These models can also be used to forecast the system-wide effects of larger scale water level manipulations or the cumulative impacts of several smaller-scale projects (e.g., 1-D UNET, HEC-RAS).

Efforts of the model and integration subgroup should be directed towards matching the capabilities of individual hydrology & hydraulic models with the modeling support needs of selected management and restoration actions in the UMRS. Restoration project teams and Science Panel modelers are testing dynamic hydrologic modeling capabilities and integrating them with ecological models in Pool 5. These models will be developed at low resolution as a proof of concept and then refined and exported as applicable to other projects. A new and unique hydraulic design and modeling challenge is being introduced by the objective to provide fish passage throughout the UMRS. A range of technical and naturalistic fishway designs will be considered that will require hydraulic modeling to support design and operation studies.

e. Habitat Models. The UMR-IWW System Navigation Feasibility Study Science Panel identified a number of habitat-based models that are used on the UMRS. These are the most widely applied models on the UMRS. U.S. Fish and Wildlife Service Habitat Evaluation Procedures (HEP) and community level derivations of them (e.g., Wildlife Habitat Appraisal Guide (USACE-ERDC 1990) and Aquatic Habitat Appraisal Guide (USACE-ERDC 1990)) are the most widely used models. The models typically assess physical and landcover characteristics, or both, to estimate the potential for occurrence of plant or animal species. The models are also used to assess existing conditions across large spatial areas that are not sampled (e.g., LTRMP Backwater fish winter habitat model) and also to estimate biological response to restoration alternatives. Prior model applications used spreadsheet technology, with more, recent applications having strong links to GIS and supporting databases.

The Modeling Team needs to explore existing habitat model applications and if additional tools might improve restoration planning. System scale landscape modeling is required to evaluate existing conditions and determine priorities among projects that will fill habitat gaps, provide pathways, or contribute across large spatial scales.

f. Biological Models. Prior reviews identified numerous biological models with potential application for the UMRS (Lubinski and Barko 2003). There are community, population, and individual-based models that apply at a variety of scales. The fish entrainment, fish production, fish spawning habitat, submerged aquatic plant, and mussel models developed during the UMR-IWW System Navigation Feasibility Study (Bartell et al. 2000) served as the basis for estimating inputs of increased commercial navigation traffic. Bioenergetics models of sago pondweed and water celery (NAVSAV, Best et al. 2004) were used to assess the effects of sediment resuspended by passing vessels on aquatic plant growth. Fingernail clams response to island construction in Pool 7 was modeled , and zebra mussel dispersal was modeled to assess risk throughout the system. RAMAS® GIS population model was used to assess the size of viable populations of the endangered mussel *Lampsilis higginsi*.

Recently, work has begun on the developing a version of the Comprehensive Aquatic System Model (CASM) for the UMRS. The CASM work is discussed below, but it is likely that the work will identify many additional modeling needs. Investigators and managers will find that their specific needs can be addressed and become another node within the CASM framework. The architecture is developed specifically to integrate across model components and scales.

The Modeling Team needs to help further identify, review, and recommend biological models that are useful in large-scale restoration planning. Better population models are required to understand the current abundance of life in the UMRS. Production models at individual and community scales could be extremely helpful documenting benefits of ecosystem restoration activities. A floodplain vegetation successional model is a highly desired management tool that the Modeling group should address.

The Science Panel understands that individual management and restoration actions can potentially impact many ecological resources across a wide range of ecological scales and levels of organization. A set of diverse ecological resource models will be required to meet restoration project design and implementation needs. The Panel recognizes that the ecological modeling community has produced a myriad of potentially useful models over the last two decades. Considerable efforts should be invested in systematically searching and evaluating (e.g., Pastorok et al. 2002) the ecological modeling literature to identify candidate models for inclusion in the set of models to support UMRS ecosystem management and restoration.

Several topic areas of impending ecological modeling needs include models that address community structure, production dynamics, and succession in riparian wetlands and floodplain forests; models that have similar capabilities for submerged aquatic vegetation; and models that can be used to assess the likely outcomes of management and restoration projects for an ecologically diverse set of resources (e.g., plants, fishes, aquatic invertebrates, mammals, waterfowl).

4. Application of Models

a. CASM Model. In an effort that predates the convening of the Science Panel, the CASM is being developed as a spatially explicit ecosystem model for Pool 5. Many direct, indirect, and unanticipated effects on ecological processes can result (intentionally or unintentionally) from restoration projects. Ecosystem models that address this degree of ecological complexity could be used in planning and monitoring specific ecosystem management and restoration projects. CASM is a flexible, bioenergetics-based modeling framework that allows the user to specify multiple populations of aquatic producers and consumers. CASM permits the user to define food web structure, define trophic interactions, and estimate bioenergetics parameters for modeled producers and consumers. The model simulates the daily production dynamics of modeled populations in relation to user-specified values for water depth, current velocity, light intensity, water temperature, and dissolved nutrients (N, P, Si). This model also simulates decomposition processes, dissolved oxygen concentration, and nutrient cycling.

In 'proof of concept' and as a logical extension of the ecological models used to assess impacts during the Navigation Feasibility Study, the CASM has been integrated with a series of RMA-2 simulations (over a range of river discharge) and implemented for Pool 5. In this initial integration, the values of water depth, current velocity, and hydraulic exchange produced by the RMA-2 for different flow scenarios were used directly as CASM input values. The ecological data necessary to apply CASM to Pool 5 were obtained from on existing studies on Pool 5, data from the nearby Environmental Management Program Finger Lakes, Pool 5, biological response study, the technical literature, and LTRMP data. The CASM has been developed within a risk assessment framework with propagation of uncertainties through the model system with Monte Carlo simulation to examine the implications (e.g., ecological 'surprises') of the many sources of variability and uncertainty inherent to ecosystem modeling and ecological forecasting.

The integrated CASM model can be used to characterize the potential direct and indirect results of management or restoration actions (e.g., drawdown) that alter flows and elevations in Pool 5. For example, the CASM might be able to predict the production of aquatic plants in relation to projects that influence ambient turbidity, water depth, grazing, epiphytic cover, and current velocity. The model might also provide clues concerning the spatial distribution of SAV within the navigation pool. Innovative uses of CASM might permit estimates of ecological responses that are difficult to measure. For example, larval fish density data can be used to estimate the abundance of fish in a specific river segment by projecting fish survival to future adult abundance. This approach might be used to evaluate the potential effects of management actions on fish reproduction and fish population sizes in the absence of expensive fish stock assessments. The integrated CASM might also be used to help design monitoring needed to provide statistically robust inferences about ecological effects of projects.

b. ADH Model. The Pool 5 site was also selected for advance hydraulic modeling to provide the hydraulic data needed for CASM. The existing 2-D hydraulic model is going to be upgraded from a static model run under various hydrologic conditions to a dynamic model that integrates across ranges of river discharge. This is an early application of the model, which when refined, will likely become very useful in restoration project design and planning system-wide. Integrating the ADH model, CASM models, and refined individual-based bioenergetics models can provide effective planning tools for the NESP.

These are examples of potentially useful ecosystem models to support management and restoration in relation to the NESP. Other models will also be adapted for use in the Upper Mississippi River. Modeling needs and capabilities should be reexamined and evaluated frequently for potential application to management and restoration under the NESP.

G. Discussion

Ecological modelers among the UMRS river management community can be broadly separated into the following categories:

- researchers engaged in a blend of basic and applied research,
- applied scientists and engineers who focus on developing technologies that agencies can use to execute their resource planning and management activities, and
- agency representatives who use the tools to fulfill their agency's mission.

Each of the categories of participants has their own perspective on the way forward. The integration of these different perspectives has led to the Modeling Team recommendations. Each of the perspectives is emphasized below followed by an integrating summary section. For brevity, we combine the perspective of the applied and basic researchers.

1. Perspective of the Model User

The subset of the Modeling Team workshop attendees representing the model user community requested that the model system developed to support the UMRS should have the following attributes:

- Address management and restoration actions across relevant UMRS spatial and temporal scales
- Provide modeling tools of different complexity and resolution
- Guide in the selection and use of specific modeling tools
- Provide model results in a form easily used in decision-making
- Assist in the design and planning of multiple projects
- Assist in characterization of historical and current conditions
- Contribute to development of the future desired condition
- Describe cumulative impacts and benefits
- Reflect the issues and concerns of stakeholders and partners

2. Perspective of the Model Builders

These members of the Science Panel are generally focused on the technical quality and scientific defensibility of the models used to support decision-making. The following recommendations and expectations were identified. They can be categorized as follows: general recommendations that affect all models, recommendations associated with implementing adaptive management, and recommendations on specific topic areas. Generally, ecosystem models need to:

- Explicitly characterize uncertainties associated with model forecasts
- Improve prediction of ecosystem response
- Link Ecosystem Processes - Functions - Services

H. Future Role of the Science Panel in Ecological Modeling

The model integration workshop featured contributions from members of the Science Panel and others that likely identified the majority of science and implementation issues associated with the NESP. Literature review and consultation with other experts were also important to address modeling and integration needs. Our review identified the following program elements and principles. It is important that the Modeling Team continue its involvement to ensure these important elements and principles are achieved.

1. Procedures to ensure the quality and defensibility of all modeling tools

Explicit steps should be established to ensure that modeling tools are of maximum technical quality and demonstrated scientific defensibility. These steps can be broadly separated into optimum knowledge utilization; guidelines for interrelating models that predict status of similar Essential Ecosystem Components, but at different levels of physical and ecological detail; and methods to assist decision-makers in assessing uncertainty in model predictions.

2. Ecological modeling similitude analysis

Typically, PDTs and system-level decision-makers prefer using the least complex models possible because the results are clear and the tools are simple to use. However, scientists typically employ high resolution modeling tools to better understand processes and describe cause-effect relationships. In some cases (particularly in ecology), the tradeoff between model complexity and answer quality is unclear. In cases where this tradeoff is not clear, we recommend that use of ecological model similitude analysis to prevent the use of overly complex models. In this analysis, calibrated high resolution models are recursively simplified by coarsening time and space scales, reducing model structural complexity, and eliminating or consolidating coefficients. At each stage of simplification, sensitivity and divergence analysis should be used to identify the point at which the simple model output diverges from the high resolution model results (or measured values if they are available) to the point that project decisions would be altered. The model configuration immediately prior to this point should be considered the most parsimonious model that can be used to support decision-making. It may also be possible to work backwards from the decision making process to understand how much detail is needed to make decisions. For example, in many cases habitat models may be a simple and defensible surrogate for some population models but the appropriateness and justification of such replacement must be documented.

3. Connect ecological modeling system to higher order decision-making tools

Ecological modeling contributes one piece of summary information towards system-level decision-making that supplements economic projections and social impacts provided by models developed and run by other groups within NESP. The most efficient way to achieve this objective is make sure that the model can translate management actions into ecological response results that can be evaluated relative to UMRS ecosystem goals and objectives (particularly for ecological response) and provide input to indicators used for report record preparation and reporting. We recommend that the summary output of the ecosystem-level models be consistent with the input needs of higher order decision-making tools that will be developed to assist in the analysis of system-wide benefits and costs.

4. Develop Guidance for the Project Delivery Teams on model selection and utilization

We anticipate that the PDTs or their contractors will be the primary model user group. To ensure continuity of model selection and use, we recommend that tool section guidance document be created that features a matrix of management action (rows) x physical/morphological/geochemical/biological process (columns) with each cell containing a listing of acceptable tools by scale (project/pool/reach/system), model complexity, and ecosystem components. In addition, we recommend that regular (perhaps annual) modeling training be conducted to regularly train model users in model selection, utilization, and available upgrades.

5. Develop Protocols for institutionalizing Models and Modeling in PDT activities

Modeling is a critical component of adaptive management and therefore procedures must be established to ensure that models contribute to the success of the NESP. We recommend that project planning include the following elements:

- a description of the anticipated ecosystem response to the management actions embodied in the project;
- a description of the assumptions made in anticipating project performance;
- a description of the importance of the project to system-level goals made in collaboration with the Science Panel;
- a description of the “opportunity for learning” provided by the project relative to other similar projects in NESP;
- a recommended level of monitoring investment relative to system-level goals; and
- a detailed monitoring plan

After monitoring data have been collected and assessed, the PDTs with assistance from the Science Panel, should prepare a supplement to the project plan that includes the following elements:

- confirm those responses to management action that were expected;
- highlight responses that violated assumptions or were different than predicted by planning models;
- describe responses that would indicate the presence of a new or misrepresented process;
- resolve uncertainties targeted by the monitoring plan; and
- provide a summary of improvements needed in the planning, assessment, or summarization tools to update to accommodate the new knowledge obtained from the project. The summary should be transferred to the System-Scale PDT as a task. This last step institutionalizes learning about the system and concludes one iteration of adaptive management.

8 Future Science Panel Activities

The adaptive management approach requires much attention to the proper application and performance of restoration activities. The Science Panel needs to increase its involvement with the Program in all aspects of the adaptive management process. There are ongoing institutional and science support needs, as well as short term planning needs that should to be addressed immediately.

A. Institutional Support to NESP

The NESP institutional arrangements are not complete, but there are some assumptions and constraints that are currently guiding development of these arrangements. The fundamental components of the NESP institutions may include (figure 1):

- Federal Principals Group
- Upper Mississippi River Basin Association
- River Council
- Science Panel
- Communication Panel
- River Teams
- Work Groups
- Project Delivery Teams

Components of institutional arrangements for connection to high-level decision makers and broader basin management include the Upper Mississippi River Basin Association, Regional Principals (Federal and State agency Directors), and Federal Principals (Agency Directors and Secretaries). The Principals consider UMRS issues in the context of other National and regional priorities. They can direct agency efforts toward river issues and work with Congress for support of UMRS issues.

A River Council operates over the entire UMRS (scale) and addresses two focus areas, one being the ecological health of the UMRS and the other navigation efficiency, reliability, and safety. The River Council's purpose is to share information and work toward common understanding on vision, goals, objectives, management priorities, performance, and communication concerning navigation efficiency, reliability, and safety and the ecological health of the UMRS. This group consists of representatives of federal and state agencies and non-government organizations covering transportation, economic, and ecological responsibilities.

River Teams align geographically with specific river reaches (i.e., Corps Districts), and there are four river reaches, three on the Mississippi and one for the Illinois Waterway work toward common understanding on vision, goals, objectives, management priorities, performance, and communication concerning the ecological health of reaches of the UMRS and integration with operation and maintenance of the navigation system. River Teams may also share information and work toward common understanding regarding navigation efficiency, reliability, and safety.

The Science Panel is an interdisciplinary and dynamic team of scientists and engineers created under contract with the Corps for science and technical planning and studies related to ecological health of the UMRS. The Science Panel is not an interagency collaboration forum like other components of institutional arrangements. The Science Panel is neutral body, which exists to help the UMRS partnership make scientifically informed decisions. Composition and tasks of the Science Panel will be reviewed periodically by the River Council and the Corps NESP Management Team. The Science Panel will seek specific expertise when needed.

1. Science Panel Support to the River Council

The Science Panel will primarily make recommendations to the Corps for consideration in the context of Program implementation. The UMR-IWW System Navigation Feasibility Study Science Panel's adaptive management recommendation has been adopted as the Program implementation approach. The current Science Panel has refined recommendations for adaptive management planning and implementation. Recommendations cover the range of adaptive management topics covered in this report. The Science Panel structure will be flexible to address new priorities in the future.

The Science Panel will help the River Council with communication across all UMRS ecosystem components and partners. Information and results will be tailored to technical, scientific topics, administrative reviews, and public dissemination. The recommended decision support system will allow users to "drill down" through information layers to the level of detail suitable to their needs. A UMRS Ecosystem Report Card will be a periodic product meant to assess the state of the UMRS ecosystem and track it through time. The state of certain ecosystem parameters representing a range of components, processes, and structures will be gauged against desired states.

The Science Panel recommends planning for the system, thus they consider system goals and objectives, process and structure, and restoration opportunities. Other Programs and agencies are invited to work within the adaptive management framework. UMRS natural resource managers and partners will also look outward toward these programs to align objectives with agency missions.

2. Science Panel Support to River Teams and Project Delivery Teams

The Environmental Science Panel will provide guidance to the River Teams and PDTs on project objectives, modeling, and monitoring plans. The planning process used by the PDTs has several steps where Science Panel interaction could be useful (figure 3). The Science Panel responsibilities that have direct ties to the PDTs include:

- Provide scientific guidance for implementing adaptive management by:
    - evaluating the learning potential of proposed projects,
    - develop science-based recommendations for sequencing work system-wide,
    - setting outcomes and metrics for monitoring and performance evaluation at multiple scales (e.g., project, pool, system),
    - developing and implementing protocols for biological response studies,
    - evaluating and reviewing monitoring results, and
    - recommending revisions, as needed, to protocols, outcomes, goals and objectives, etc. based on results.
- Collaboratively develop a framework for creating models, including:
    - A set of working system models as tools for understanding ecosystem processes (integration of chemical, biological, hydrological, hydrodynamic, and sediment transport processes).
    - Creating models and forecasting tools to evaluate effectiveness of various ecosystem management actions.
- Provide scientific guidance for refining, expanding, or condensing goals and objectives for the ecological condition of the UMRS at the reach scale.

Resource Managers, PDTs, and the River Teams will continue to have the lead in developing goals and objectives, defining desirable responses, selecting appropriate parameters for monitoring, and choosing actions at the project and pool scale. However, these efforts could be improved if the Science Panel can provide guidance at the reach or system scales. Table 12 lists potential roles and responsibilities of PDTs and the Science Panel.

Table 12. Roles and Responsibilities of NESP Project Teams and the Science Panel

Product Delivery Teams	Science Panel
Establish Project/Pool scale goals and objectives guided by Reach and System scale goals and objectives	Refine and expand Pool/Reach scale goals and objectives. Fold into system-wide perspective.
Develop Project/Pool scale physical criteria established based on research, LTRM data base, lessons learned, natural river paradigm	Develop Pool/Reach scale physical criteria
Set Project/Pool scale performance measures	Set Pool/Reach scale outcomes
Develop hydrology and hydraulics and sediment transport models needed to design actions Refine tools (e.g. HEP, matrices, IBMs – Individual Based Population models) to assess and rank projects. Determine appropriate level of modeling. Review of historical physical, chemical, biological conditions and changes.	Collaboratively develop a set of models or tools to simulate biological response (populations) & ecological services. Provide guidance to Project Delivery Teams so models can be used in and provide information from the system perspective.
Project/Pool scale monitoring: What variables need to be monitored to determine success at the project/pool scale? What variables can we monitor that will help us learn and adapt? What data exists that hasn't been fully utilized?	What variables need to be monitored to determine success at the Pool/Reach scale? Report Card Development
Sequencing of projects within a pool. Objectives will be integrated with constraints and opportunities.	Sequencing: Establish guidelines for sequencing based on needs, outputs (i.e. chance of success), learning opportunities, synergy.

B. Science Support Activities

1. System Focus

The Science Panel should be focused on the system-scale. This emphasizes their participation as a NESP team member, albeit in a larger capacity than most teams. They need to help the NESP achieve local and reach priorities while also addressing system-wide objectives. They need to use their broad view, especially early during the NESP, as an opportunity to learn about and refine ecosystem management and restoration activities. They need to help guide implementation toward actions that will have the greatest local and system impacts. The Science Panel will interact vigorously with pool and project- scale PDTs in establishing system-wide objectives that are compatible with the interests of multiple stakeholder groups and the pubic as a whole.

Potential Science Panel activities have been discussed at length in this report, and recommendations covering all components of adaptive management have been presented to UMRS managers and partners.

Future efforts of the Science Panel should focus on:

- Project Sequencing
  - Which projects best meet system objectives?
  - What is optimal spatial distribution of individual projects?
  - How should projects be sequenced and timed for maximum system-level benefit?
  - Prioritize projects by inherent risk and uncertainty so that more detailed monitoring, modeling, and assessment can be invested in those projects where the greatest learning and uncertainty reduction can occur.
  - Protect or restore best habitat first.

- Project Assessment and Monitoring Guidelines
  - Assist PDTs in developing individual project conceptual models as a way of standardizing (as much as possible) projects across pools, reaches, and Districts.
  - Be responsible for upgrading system-level tools to maintain pace with system-level learning that occurs during adaptive environmental assessment and management.
  - Distribute monitoring effort across all projects to maximize system-level reduction in uncertainty.

- Data Analysis and Interpretation
  - Provide conceptual models, briefings, visualizations to help decision-makers explain their actions to stakeholders and the public.
  - Provide translation of ecological information used to balance among system-level societal, economic, and restoration goals.

- Research Feedback
  - Be prepared to assist the Corps with scientific quality control in ecosystem restoration to ensure the program will pass scientific peer review challenges.
  - Assist PDTs in using the decision support system so each Project Delivery Team is aware of actions of other PDTs.

- System-wide Learning
  - Insure understanding of UMRS ecosystem restoration activities by holding workshops, writing multi-authored white papers, developing conceptual models, etc.
  - Assist with the development of a decision support system that incorporates critical information about all existing and planned projects (numbering more than 1,000). The decision support system should:
    - Include a relational database of projects (including both ecological and economic data)
    - be linked to GIS to track projects.
    - Include all relevant management and decision-making information.
    - Take advantage of tools that already exist in the region.
  - Bear the primary responsibility for learning at the system level and to make recommendations to update all tools, procedures, and protocols so that new learning is institutionalized.
  - Constantly accumulate and integrate scientific uncertainties and recommend cost effective and timely R&D to address critical project and system-level uncertainties.
  - Bear the primary responsibility for analyzing and assessing system-level response to management action to develop the learning necessary to iteratively improve the effectiveness of system-wide management as part of adaptive management.

Information management for a large program like the NESP is challenging, but incredibly important from the outset. The Science Panel has recommended developing a decision support system that can integrate system-level restoration progress, benefits, and impacts from individual projects for upward reporting and summarization.

2. Recommended Science Panel Activities in 2006

It is important to continue to refine implementation plans for the NESP. One of the most important tools required is an information management system that can accommodate the planning, implementation, and evaluation data that will be produced for a large number of projects and studies. The Science Panel recommends immediate development of a decision support system that has both information technology and knowledge and information management components. The decision support system may be, or at least should access, a storage site for data developed through the various research and monitoring activities. There is potential for large amounts of data to be produced among a variety of topics.

UMRS management agencies have desired an information needs assessment for many years. There has been considerable effort devoted to environmental monitoring, but much of it has been ad hoc or single issue driven. The Science Panel recommends that UMRS managers conduct an assessment of information needed for adaptive ecosystem management including restoration planning, modeling, monitoring, and report card development. A better understanding of specific information needs will help make better environmental data acquisitions in the future.

There have been many requests of the Science Panel to provide technical input on site-specific projects and pool and reach scale project sequencing and monitoring recommendations. The Panel has been occupied developing this plan during 2005 and had only limited time to work with PDTs. The Science Panel will be available to begin working with NESP partners in 2006. The Science Panel met reach planning teams in Pools 5 and 18 and in the Open River Harlow reach during October 2005 and with the fish passage PDTs in November. The Forest Management PDT sought the opinion of the Science Panel when deciding whether to contract for the development of a vegetation successional model for the UMRS.

The Science Panel should meet with PDTs to discuss the ecosystem objectives and their application in project planning and implementation. The Science Panel should discuss information needed for project planning with PDTs to help design a decision support system.

Monitoring is a cornerstone of adaptive management. The Science Panel will make clear recommendations on the range of options for river monitoring. Several conceptual monitoring strategies are presented in this report. The Science Panel should consult with the UMRS partnership and the Corps Program Management Team about an effective monitoring strategy to support rigorous adaptive ecosystem management.

Ecological modeling is being addressed in three ways: conceptual modeling, ecosystem modeling, and detailed modeling of specific ecosystem components like the various hydrologic, sediment transport, or water quality models that are already available and extremely useful to restoration project planning. The conceptual model developed in 2003 is used to identify ecological interactions affecting existing conditions and proposed management actions. It is a helpful planning and communication tool that will be applied to more management actions in 2006. Ecosystem models are useful to predict outcomes from management actions, model components can be built at separate scales or rates and integrated into the larger model structure. The ecosystem scale approach allows planners to evaluate alternative restoration approaches during project planning. They may also be used at larger scales to evaluate alternative combinations of various projects at a large scale. The ecosystem model will be refined and perhaps exported to other part of the river. Site specific models are important to understand intricate details of ecosystem processes. They can range from models of physical processes like flow patterns and sediment movement or biological models of productivity or animal populations. A vegetation successional model has been prioritized for 2006. Modeling of hydraulic conditions occupied by fish in tailwaters will be done in 2006 to help design fish passage projects.

Modeling and monitoring activities are conducted largely to estimate and evaluate project outcomes. The outcomes are rarely, but should be, expressed as valued ecosystem services such as number of additional animals produced, flooding attenuated, or waste assimilated, for example. Project outcomes may not directly influence a valued service, in these cases their influence on valued services can be modeled. The economic value of ecosystem services has not been adequately estimated in the past, making these estimates is an important task for 2006. Over time, economic and ecological models will be coupled.

Reporting project outcomes and ecosystem condition to program partners, decision makers, and the public is an important aspect of adaptive ecosystem management. Project level outcomes will be individually reported and compiled in periodic program reports. An ecosystem report card is more general in nature, focusing on ecosystem indicators that represent important components or processes, but are well understood by the public. Indicators need to be finalized in cooperation with river stakeholders and the public in 2006. Once accepted, the indicators will need to be tracked through monitoring and reported at appropriate frequencies. Not all indicators may be on the same reporting schedule.

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Appendix A
Decision Support System Matrix Tables UMRS

Ecosystem Objectives and Indicators

NESP Objective Number	Proposed NESP Ecosystem Objectives	Indicators
	1. Water Quality	
1.1	Reduce contaminant loadings to the river	Contaminant loading rates
1.2	Reduce contaminants in the rivers	Contaminant concentrations
1.3	Reduce mobilization of sediment contaminants	Contaminant mass mobilization/dredging job
1.4	Achieve State Total Maximum Daily Loads (TMDLs)	Contaminant loading rates
1.5	Reduce sediment loadings to the rivers	Sediment loading rates
1.6	Reduce nutrient loading from tributaries to rivers	N, P loading rates
1.7	Reduce nutrient export from the UMR to Gulf of Mexico	N export rates
1.8	Maintain adequate DO concentrations for fishes	DO concentrations
1.9	Maintain water clarity sufficient to support submersed aquatic vegetation and aquatic invertebrates and sight feeding fishes	PAR, Secchi transparency, turbidity
	2. Geomorphology	
2.1	Modify main channel border areas	Area, geometry, substrate type, current velocity in channel border areas
2.2	Modify secondary channels	Area, number, geometry, substrate type, current velocity of secondary channels
2.3	Modify tertiary channels	Area, number, geometry, substrate type, current velocity, vegetation of tertiary channels
2.4	Modify the channels and floodplains of tributary rivers	Number, area of tributary channels, geometry of channels and floodplains
2.5	Increase the extent and number of sand bars	Number, area of sand bars
2.6	Increase the extent and number of mud flats	Number, area of mud flats
2.7	Increase the extent and number of gravel bars	Number, area of gravel bars
2.8	Increase the extent and number of islands	Number, area of islands
2.9	Increase the extent and number of rock and gravel riffles and substrate areas	Number, area of rock and gravel riffles
2.10	Increase topographic diversity and elevation of floodplain areas	Number, area of rock and grave substrate areas
2.11	Modify delta areas	Number, area of modified floodplain areas
2.12	Modify connectivity between channels and contiguous backwater areas	Percent of river discharge flowing through backwater area
2.13	Modify connectivity of floodplain areas	Percent of river discharge flowing through floodplain areas
2.14	Modify contiguous backwater areas	Number, area of modified contiguous backwater areas
2.15	Increase the number and extent of isolated floodplain lakes	Number, area of geomorphic area types and floodplain features
	3. Hydrology/River Hydraulics	
3.1	Naturalize hydrologic regime of main-channels	Discharge hydrograph
3.2	Reduce stage and discharge fluctuations caused by dam operation	Stage hydrograph
3.3	Restore a more natural hydrologic regime in the navigation pools	Stage hydrograph
3.4	Restore a more natural hydrologic regime in floodplain waterbodies	Stage hydrograph
3.5	Naturalize hydrologic regime of tributaries	Stage hydrograph
3.6	Increase storage and conveyance of flood water on the floodplain	Area of modified floodplain
3.7	Reduce wind fetch in open water areas	Wind fetch length
	4. Habitat	
4.1	Provide desirable pattern of hydraulic conditions in tailwaters for fishes	Current velocity
4.2	Provide pathways for animal movements	Number of [species] passing barrier
4.3	Modify the extent, patch size and succesionnal variety of plant communities	Landscape metrics
4.4	Modify the extent, abundance and diversity of submersed aquatic plants	Landscape metrics
4.5	Modify the extent, abundance and diversity of emergent aquatic plants	Landscape metrics
4.6	Restore and maintain large contiguous patches of plant communities	Landscape metrics
4.7	Modify backwaters to provide suitable habitat for fishes	Landscape metrics
4.8	Modify channels to provide suitable habitat for fishes	Landscape metrics
4.9	Increase the number and extent of managed marsh areas in leveed floodplain	Landscape metrics
4.10	Increase habitat corridor sizes and connectivity	Landscape metrics
4.11	Increase vegetated riparian buffers along tributaries and ditches in the floodplain	Landscape metrics
4.12	Increase woody debris in channels	Landscape metrics
	5. Biota	
5.1	Maintain viable populations of native species throughout their range in the UMRS at levels of abundance in keeping with their biotic potential	Indicators of animal abundance
5.2	Maintain the diversity and extent of native communities throughout their range in the UMRS	Indicators of community diversity
5.3	Reduce the adverse effects of invasive species on native biota	Indicators of plant and animal abundance

UMRS Ecosystem Objectives and Action Agencies "X" = Responsible Action Agencies

NESP Objective Number	Proposed NESP Ecosystem Objectives	Corps	USFWS	EPA	NRCS	States	Municipalities	Industries	Watershed Organizations	NGOs	Contractors	Landowners
	1. Water Quality											
1.1	Reduce contaminant loadings to the river			X		X	X	X				
1.2	Reduce contaminants in the rivers	X				X					X	
1.3	Reduce mobilization of sediment contaminants	X				X					X	
1.4	Achieve State Total Maximum Daily Loads (TMDLs)			X	X	X	X	X	X			
1.5	Reduce sediment loadings to the rivers			X	X	X	X		X		X	X
1.6	Reduce nutrient loading from tributaries to rivers			X	X	X	X	X	X			X
1.7	Reduce nutrient export from the UMR to Gulf of Mexico			X	X	X	X	X	X		X	X
1.8	Maintain adequate DO concentrations for fishes	X	X			X						
1.9	Maintain water clarity sufficient to support submersed aquatic vegetation and aquatic invertebrates and sight feeding fishes	X	X			X						
	2. Geomorphology											
2.1	Modify main channel border areas	X	X			X						
2.2	Modify secondary channels	X	X			X						
2.3	Modify tertiary channels	X	X			X						
2.4	Modify the channels and floodplains of tributary rivers	X	X			X						
2.5	Increase the extent and number of sand bars	X	X			X						
2.6	Increase the extent and number of mud flats	X	X			X						
2.7	Increase the extent and number of gravel bars	X	X			X						
2.8	Increase the extent and number of islands	X	X			X						
2.9	Increase the extent and number of rock and gravel riffles and substrate areas	X	X			X						
2.10	Increase topographic diversity and elevation of floodplain areas	X	X			X						
2.11	Modify delta areas	X	X			X						
2.12	Modify connectivity between channels and contiguous backwater areas	X	X			X						
2.13	Modify connectivity of floodplain areas	X	X			X				X		X
2.14	Modify contiguous backwater areas	X	X			X						
2.15	Increase the number and extent of isolated floodplain lakes	X	X			X				X		X
	3. Hydrology/River Hydraulics											
3.1	Naturalize hydrologic regime of main-channels	X			X	X		X	X			X
3.2	Reduce stage and discharge fluctuations caused by dam operation	X	X			X		X				
3.3	Restore a more natural hydrologic regime in the navigation pools	X	X			X		X				
3.4	Restore a more natural hydrologic regime in floodplain waterbodies	X	X			X				X		X
3.5	Naturalize hydrologic regime of tributaries	X			X	X		X	X			X
3.6	Increase storage and conveyance of flood water on the floodplain	X	X		X	X				X		X
3.7	Reduce wind fetch in open water areas	X	X			X						
	4. Habitat											
4.1	Provide desirable pattern of hydraulic conditions in tailwaters for fishes	X	X			X		X				
4.2	Provide pathways for animal movements	X	X			X						
4.3	Modify the extent, patch size and succesionnal variety of plant communities	X	X			X				X		X
4.4	Modify the extent, abundance and diversity of submersed aquatic plants	X	X			X						
4.5	Modify the extent, abundance and diversity of emergent aquatic plants	X	X			X						
4.6	Restore and maintain large contiguous patches of plant communities	X	X			X				X		X
4.7	Modify backwaters to provide suitable habitat for fishes	X	X			X						
4.8	Modify channels to provide suitable habitat for fishes	X	X			X						
4.9	Increase the number and extent of managed marsh areas in leveed floodplain	X	X			X						
4.10	Increase habitat corridor sizes and connectivity	X	X			X						
4.11	Increase vegetated riparian buffers along tributaries and ditches in the floodplain	X	X			X						
4.12	Increase woody debris in channels											
	5. Biota											
5.1	Maintain viable populations of native species throughout their range in the UMRS at levels of abundance in keeping with their biotic potential	X	X			X				X		X
5.2	Maintain the diversity and extent of native communities throughout their range in the UMRS	X	X			X				X		X
5.3	Reduce the adverse effects of invasive species on native biota	X	X			X						

UMRS Ecosystem Objectives and Management Actions "X" = Potential Objectives

NESP Objective Number	Proposed NESP Ecosystem Objectives	Floodplain Forest and Grasslands Restoration	Islands Building	Fish Passage Improvements	Floodplain Connectivity Restoration	Water Level Management	Secondary Channel Restoration	Backwater Restoration	Wing Dam, Closing Dam Modifications	Island and Shoreline Protection	Floodplain Topographic Diversity Restoration	Change River Regulation to Dam Point Control	Dam Embankments Modifications	Reduce Illinois River Water Level Fluctuations
	1. Water Quality													
1.1	Reduce contaminant loadings to the river													
1.2	Reduce contaminants in the rivers													
1.3	Reduce mobilization of sediment contaminants													
1.4	Achieve State Total Maximum Daily Loads (TMDLs)													
1.5	Reduce sediment loadings to the rivers							X						
1.6	Reduce nutrient loading from tributaries to rivers							X						
1.7	Reduce nutrient export from the UMR to Gulf of Mexico				X			X						
1.8	Maintain adequate DO concentrations for fishes					X		X						
1.9	Maintain water clarity sufficient to support submersed aquatic vegetation and aquatic invertebrates and sight feeding fishes					X		X						
	2. Geomorphology													
2.1	Modify main channel border areas		X						X	X		X		
2.2	Modify secondary channels		X				X	X	X	X				
2.3	Modify tertiary channels						X	X	X		X			
2.4	Modify the channels and floodplains of tributary rivers	X			X			X			X			
2.5	Increase the extent and number of sand bars		X			X	X		X	X		X	X	
2.6	Increase the extent and number of mud flats		X			X	X		X	X		X	X	
2.7	Increase the extent and number of gravel bars		X			X	X		X	X		X	X	
2.8	Increase the extent and number of islands		X						X	X			X	
2.9	Increase the extent and number of rock and gravel riffles and substrate areas		X				X		X	X			X	
2.10	Increase topographic diversity and elevation of floodplain areas	X			X						X			
2.11	Modify delta areas	X			X	X		X			X			
2.12	Modify connectivity between channels and contiguous backwater areas		X			X	X	X	X	X		X	X	X
2.13	Modify connectivity of floodplain areas	X	X		X	X	X	X			X		X	
2.14	Modify contiguous backwater areas		X			X	X	X	X	X		X	X	X
2.15	Increase the number and extent of isolated floodplain lakes				X			X			X			
	3. Hydrology/River Hydraulics													
3.1	Naturalize hydrologic regime of main-channels					X						X		X
3.2	Reduce stage and discharge fluctuations caused by dam operation					X						X		X
3.3	Restore a more natural hydrologic regime in the navigation pools					X						X		X
3.4	Restore a more natural hydrologic regime in floodplain waterbodies					X	X	X	X		X	X	X	
3.5	Naturalize hydrologic regime of tributaries							X						
3.6	Increase storage and conveyance of flood water on the floodplain	X			X		X	X			X			
3.7	Reduce wind fetch in open water areas		X					X		X				
	4. Habitat													
4.1	Provide desirable pattern of hydraulic conditions in tailwaters for fishes			X					X				X	
4.2	Provide pathways for animal movements			X			X			X			X	
4.3	Modify the extent, patch size and succesionnal variety of plant communities	X	X		X	X		X		X	X		X	
4.4	Modify the extent, abundance and diversity of submersed aquatic plants		X		X	X	X	X	X	X	X	X	X	X
4.5	Modify the extent, abundance and diversity of emergent aquatic plants		X		X	X	X	X	X	X	X	X	X	X
4.6	Restore and maintain large contiguous patches of plant communities	X			X	X		X			X			
4.7	Modify backwaters to provide suitable habitat for fishes		X		X	X	X	X	X	X		X	X	X
4.8	Modify channels to provide suitable habitat for fishes		X		X		X		X	X			X	X
4.9	Increase the number and extent of managed marsh areas in leveed floodplain					X								
4.10	Increase habitat corridor sizes and connectivity	X		X	X	X	X	X			X		X	
4.11	Increase vegetated riparian buffers along tributaries and ditches in the floodplain	X			X						X			
4.12	Increase woody debris in channels		X				X		X	X			X	
	5. Biota													
5.1	Maintain viable populations of native species throughout their range in the UMRS at levels of abundance in keeping with their biotic potential	X	X	X	X	X	X	X	X	X	X	X	X	X
5.2	Maintain the diversity and extent of native communities throughout their range in the UMRS	X	X	X	X	X	X	X	X	X	X	X	X	X
5.3	Reduce the adverse effects of invasive species on native biota	X	X	X	X	X	X	X	X	X	X	X	X	X

UMRS Ecosystem Objectives and Goals "X" = Objective May Contribute to Attaining Goal

NESP Objective Number	Proposed NESP Ecosystem Objectives	Grumbine Goals	Maintain viable populations of native species in situ	Represent all native communities across their natural range of variation	Restore and maintain evolutionary and ecological processes	Integrate human uses and occupancy within these constraints	UMRCC - Audubon Goals	Improve water quality for all uses	Reduce erosion and sediment impacts	Restore natural floodplain	Restore natural hydrology	Increase backwater connectivity with main channel	Increase side channel, island, shoal, and sand bar habitat	Minimize or eliminate dredging impacts	Sever pathways for exotic species introductions/dispersal	Improve native fish passage at dams
	1. Water Quality															
1.1	Reduce contaminant loadings to the river		X		X	X		X								
1.2	Reduce contaminants in the rivers		X		X			X	X					X		
1.3	Reduce mobilization of sediment contaminants		X		X	X		X	X					X		
1.4	Achieve State Total Maximum Daily Loads (TMDLs)		X		X	X		X	X					X		
1.5	Reduce sediment loadings to the rivers		X		X	X		X	X							
1.6	Reduce nutrient loading from tributaries to rivers		X		X	X		X								
1.7	Reduce nutrient export from the UMR to Gulf of Mexico		X		X	X		X								
1.8	Maintain adequate DO concentrations for fishes		X	X	X			X								
1.9	Maintain water clarity sufficient to support submersed aquatic vegetation and aquatic invertebrates and sight feeding fishes		X	X	X			X								
	2. Geomorphology															
2.1	Modify main channel border areas		X	X	X	X						X	X			
2.2	Modify secondary channels		X	X	X	X			X		X	X	X			
2.3	Modify tertiary channels		X	X	X				X	X	X	X				
2.4	Modify the channels and floodplains of tributary rivers		X	X	X	X				X	X					
2.5	Increase the extent and number of sand bars		X	X	X	X							X	X		
2.6	Increase the extent and number of mud flats		X	X	X								X	X		
2.7	Increase the extent and number of gravel bars		X	X	X								X	X		
2.8	Increase the extent and number of islands		X	X	X	X							X	X		
2.9	Increase the extent and number of rock and gravel riffles and substrate areas		X	X	X	X							X	X		
2.10	Increase topographic diversity and elevation of floodplain areas		X	X	X	X				X	X					
2.11	Modify delta areas		X	X	X	X				X	X					
2.12	Modify connectivity between channels and contiguous backwater areas		X	X	X			X	X	X	X	X	X			
2.13	Modify connectivity of floodplain areas		X	X	X	X		X		X	X					
2.14	Modify contiguous backwater areas		X	X	X			X	X		X	X	X			
2.15	Increase the number and extent of isolated floodplain lakes		X	X	X					X	X					
	3. Hydrology/River Hydraulics															
3.1	Naturalize hydrologic regime of main-channels		X	X	X	X					X					
3.2	Reduce stage and discharge fluctuations caused by dam operation		X	X	X	X					X					
3.3	Restore a more natural hydrologic regime in the navigation pools		X	X	X	X		X			X					
3.4	Restore a more natural hydrologic regime in floodplain waterbodies		X	X	X			X		X	X					
3.5	Naturalize hydrologic regime of tributaries		X	X	X	X		X	X		X					
3.6	Increase storage and conveyance of flood water on the floodplain		X	X	X	X		X		X	X					
3.7	Reduce wind fetch in open water areas		X	X	X			X	X				X			
	4. Habitat															
4.1	Provide desirable pattern of hydraulic conditions in tailwaters for fishes		X	X	X	X										X
4.2	Provide pathways for animal movements		X	X	X	X										X
4.3	Modify the extent, patch size and succesionnal variety of plant communities		X	X	X			X	X	X			X			
4.4	Modify the extent, abundance and diversity of submersed aquatic plants		X	X	X			X	X				X			
4.5	Modify the extent, abundance and diversity of emergent aquatic plants		X	X	X			X	X				X			
4.6	Restore and maintain large contiguous patches of plant communities		X	X	X	X				X						
4.7	Modify backwaters to provide suitable habitat for fishes		X	X	X			X	X			X	X			
4.8	Modify channels to provide suitable habitat for fishes		X	X	X	X							X			
4.9	Increase the number and extent of managed marsh areas in leveed floodplain		X	X		X										
4.10	Increase habitat corridor sizes and connectivity		X	X	X					X		X	X			
4.11	Increase vegetated riparian buffers along tributaries and ditches in the floodplain		X	X	X	X		X	X	X						
4.12	Increase woody debris in channels		X	X	X								X			
	5. Biota															
5.1	Maintain viable populations of native species throughout their range in the UMRS at levels of abundance in keeping with their biotic potential		X	X	X			X	X	X						
5.2	Maintain the diversity and extent of native communities throughout their range in the UMRS		X	X	X			X	X	X						
5.3	Reduce the adverse effects of invasive species on native biota		X	X	X			X							X	

UMRS Ecosystem Objectives and Services "X" = Objective May Contribute to Service

NESP Objective Number	Proposed NESP Ecosystem Objectives	Service Types: Provisioning													Maintenance								Cultural	
		Municipal water supply	Residential water supply (groundwater)	Industrial process and cooling water	Irrigation water	Livestock watering	Hydroelectric power	Commercial navigation	Waste assimilation, purification	Food production (fish, wildlife, plants)	Construction materials and fiber from floodplain forests	Sand and gravel for construction materials	Medicinal compounds	Genetic resources	Maintenance of aquatic and floodplain habitats	Maintenance of biodiversity	Moderation of local climate	Attenuation of floods	Nutrient cycling	Carbon sequestering, protection of atmosphere	Oxygen production, protection of atmosphere	Generation and renewal of floodplain soils	Recreation	Aesthetic beauty, spiritual, cultural values
	1. Water Quality																							
1.1	Reduce contaminant loadings to the river	X	X	X	X	X			X	X						X								
1.2	Reduce contaminants in the rivers	X							X	X						X								
1.3	Reduce mobilization of sediment contaminants	X							X	X						X								
1.4	Achieve State Total Maximum Daily Loads (TMDLs)	X				X			X	X					X	X							X	X
1.5	Reduce sediment loadings to the rivers	X		X		X			X	X					X	X			X	X	X	X	X	X
1.6	Reduce nutrient loading from tributaries to rivers									X					X	X					X		X	X
1.7	Reduce nutrient export from the UMR to Gulf of Mexico									X					X	X					X		X	X
1.8	Maintain adequate DO concentrations for fishes									X					X	X					X		X	
1.9	Maintain water clarity sufficient to support submersed aquatic vegetation and aquatic invertebrates and sight feeding fishes								X	X			X	X	X	X			X	X	X		X	X
	2. Geomorphology																							
2.1	Modify main channel border areas							X		X		X			X	X							X	
2.2	Modify secondary channels							X		X		X			X	X							X	X
2.3	Modify tertiary channels									X					X	X							X	X
2.4	Modify the channels and floodplains of tributary rivers							X	X	X					X	X		X	X	X	X	X	X	X
2.5	Increase the extent and number of sand bars									X					X	X							X	X
2.6	Increase the extent and number of mud flats									X					X	X							X	X
2.7	Increase the extent and number of gravel bars									X					X	X							X	X
2.8	Increase the extent and number of islands									X					X	X	X						X	X
2.9	Increase the extent and number of rock and gravel riffles and substrate areas									X					X	X							X	
2.10	Increase topographic diversity and elevation of floodplain areas								X	X			X	X	X	X		X	X	X	X	X	X	X
2.11	Modify delta areas								X	X			X	X	X	X		X	X	X	X	X	X	X
2.12	Modify connectivity between channels and contiguous backwater areas								X	X					X	X		X	X	X	X		X	X
2.13	Modify connectivity of floodplain areas								X	X					X	X	X	X	X	X	X	X	X	X
2.14	Modify contiguous backwater areas								X	X					X	X			X	X	X		X	X
2.15	Increase the number and extent of isolated floodplain lakes								X	X					X	X	X	X	X	X	X	X	X	X
	3. Hydrology/River Hydraulics																							
3.1	Naturalize hydrologic regime of main-channels						X		X	X					X	X			X	X	X		X	X
3.2	Reduce stage and discharge fluctuations caused by dam operation							X	X	X					X	X							X	
3.3	Restore a more natural hydrologic regime in the navigation pools								X	X					X	X			X	X	X		X	X
3.4	Restore a more natural hydrologic regime in floodplain waterbodies								X	X					X	X			X	X	X		X	X
3.5	Naturalize hydrologic regime of tributaries						X		X	X					X	X			X	X	X	X	X	X
3.6	Increase storage and conveyance of flood water on the floodplain		X						X	X					X	X		X	X	X	X	X		
3.7	Reduce wind fetch in open water areas								X	X					X	X	X		X	X	X		X	X
	4. Habitat																							
4.1	Provide desirable pattern of hydraulic conditions in tailwaters for fishes									X					X	X							X	
4.2	Provide pathways for animal movements									X					X	X							X	X
4.3	Modify the extent, patch size and succesionnal variety of plant communities									X	X		X	X	X	X	X	X	X	X	X	X	X	X
4.4	Modify the extent, abundance and diversity of submersed aquatic plants								X	X					X	X			X	X	X		X	X
4.5	Modify the extent, abundance and diversity of emergent aquatic plants								X	X					X	X			X	X	X		X	X
4.6	Restore and maintain large contiguous patches of plant communities								X	X	X				X	X	X	X	X	X	X	X	X	X
4.7	Modify backwaters to provide suitable habitat for fishes								X	X					X	X							X	X
4.8	Modify channels to provide suitable habitat for fishes								X	X					X	X							X	X
4.9	Increase the number and extent of managed marsh areas in leveed floodplain									X					X	X			X	X	X		X	
4.10	Increase habitat corridor sizes and connectivity								X	X					X	X			X	X	X	X	X	X
4.11	Increase vegetated riparian buffers along tributaries and ditches in the floodplain								X	X					X	X			X	X	X	X	X	
4.12	Increase woody debris in channels									X					X	X				X		X	X	
	5. Biota																							
5.1	Maintain viable populations of native species throughout their range in the UMRS at levels of abundance in keeping with their biotic potential									X			X	X	X	X			X	X	X	X	X	X
5.2	Maintain the diversity and extent of native communities throughout their range in the UMRS									X			X	X	X	X			X	X	X	X	X	X
5.3	Reduce the adverse effects of invasive species on native biota									X					X	X			X	X	X	X	X	X

Appendix B
Project Evaluation Criteria Definitions

Ecological Consideration	Criteria	Definition
Contribution To Learning		
	Incorporates a novel experimental approach	Project includes management actions that have never been used, not used in a large river application, or are being used differently than in previous applications.
	Fits within experimental design/approach	Project has a complete pre and post project monitoring plan, or a set of projects (replicates) incorporating similar actions are monitored jointly. Monitoring control sites could also be included in the design.
	Incorporates effective monitoring plan	Project has pre and post project monitoring of relevant parameters including physical and biotic responses.
	Likely to result in fundamental knowledge gain	Projects that develop techniques to solve perennial problems can result in fundamental knowledge gains. Some examples include introducing flow into backwaters and observing the habitat and fish response (Finger Lakes), vegetation response to pool drawdowns, or fish use of by-pass channels.
	Likely to result in management innovations	Techniques that are proven cost effective and ecologically beneficial are likely to result in management innovations. Dike alterations in the MMR, flow introductions into backwaters and pool scale drawdowns are recent examples of innovations that are now commonly used tools.
Benefits Over Multiple Scales		
	Improves connectivity laterally	Lateral connectivity may be enhanced in terms of connecting backwaters and floodplains, or may be reduced by constructing barrier islands in large impounded areas
	Improves connectivity longitudinally	Increased longitudinal connectivity past navigation dams through fishways, gate operations, spillway alterations, etc.
	Achieve cumulative/synergistic habitat improvements (greater than additive)	Project may provide key seasonal habitat (staging, overwintering, breeding, etc.) that has population benefits beyond the local area or season for which it was designed.
	Emulate natural temporal patterns	Project includes features or operational changes that permits water regulation strategies that mimic natural hydrology and matches the temporal component of species life histories (e.g., reproductive timing, overwintering, etc.).
Sustainability		
	Requires minimal on-going intervention to maintain desired future state	Operation and maintenance activities to maintain optimal conditions for species, communities, and ecosystem components are considered to be routine, infrequent, and at low cost relative to the project cost. Activities may or may not occur on a regular basis.
	Scale of maintenance activity is small relative to overall project activities.	The footprint of maintenance activities should not exceed a critical threshold (acreage, volume, appropriate measurement for activity) in relation to other non-maintenance activities that occur within or at the project.
	Improves stability of project outcomes/services	Activities undertaken enhance the perpetuation of ecological processes and maintenance of optimal conditions.
	Restores natural river processes	Activities return the river's ability to maintain geomorphological, sediment flushing, nutrient cycling, biotic migrations, etc. for self-maintenance and regulation.
Critical Habitat Gains		
	Replaces lost habitat (i.e. historical assessments)	Objectives which quantify expected changes based on interpretation of available historical photographs or spatial data layers at the appropriate scale.
	Maintains desirable habitat	Project identifies key ecosystem or community component(s) that will be more cost effective to maintain at the present time than rehabilitate or restore after degradation
	Modifies or improves existing conditions	Project identifies an assessment of existing conditions on the UMRS based upon a temporal reference conducted at system, river, river reach, and pool scales.
	Meets desired future condition	Project proposes goals or objectives for an area at a future reference time as formulated during planning processes to achieve optimal conditions for species, communities, and ecosystem components

Ecological Consideration	Criteria	Definition
	Habitat Needs Assessment	Project partly achieves HNA stated acreage objectives.
	UMRCC Objectives	Project addresses one or more of the UMRCC "River that works…" goals.
	UMR-IWW Environmental Objectives	Project addressed one or more objectives of the UMR-IWW Environmental Objectives.
	MMR Side Channel Plan	Project addressed one or more of the MMR Side Channel Restoration objectives
	MMR Dike Plan	Project addressed one or more of the MMR Dike Alteration objectives
	IL Ecosystem Study/IL2020	Project addresses one or more of the goals for the Illinois River ecosystem
	USFWS-NWR CCPs	Project helps achieve the objectives of the USFWS Conservation Plan.
	State Management Plans	Project achieves the objectives of state's [site] management plans..
	Other Conservation Plans (NAWMP, Joint Venture, Shorebird Plan, etc.)	Project achieves the objectives of [ ] management plan.
	Add other plans as required	
	Channel formation	Increase number and area of secondary channels; restore channel geometry and floodplains of tributary rivers; restore channel geometry of tertiary channels.
	Channel sedimentation	Channel sedimentation refers to the filling of channels or the blockage of secondary channel inlets or outlets.
	Channel migration	Channel migration occurs where islands or shorelines are eroded on one side of a channel and deposited on the other resulting in a lateral or downstream shift of the channel.
	Filling between wingdams	Filling between wing dams refers to the process where sediments are trapped between wing dams extending into the main channel. The process results in the loss of channel border habitat to terrestrial habitat.
	Shoreline erosion	Shoreline erosion refers to active bank cutting or wasting by either river flow or boat propeller wash.
	Backwater formation	Channel formation occurs where islands are dissected and new channels flow thru what had previously been island land area.
	Backwater sedimentation	Backwater sedimentation refers to the loss of area or depth in contiguous backwaters because of filling with sediment.
	Bathymetric diversity	Loss of bathymetric diversity refers mostly to the filling of floodplain depressions, channels, and overflow channels that were inundated with the development of the navigation system.
	Sediment quality	Sediment quality refers to either the chemical composition or physical characteristics of river sediments. Toxic contaminants are an issue near urban areas especially, nutrient enrichment is prevalent in many areas. Fine sediment deposition, silt, that can be resuspended by waves is a prominent issue causing loss of submersed aquatic plants.
	Backwater delta formation	Delta formation refers to the creation of landmasses from main channel sediment deposition into backwater lakes or from tributaries entering backwaters.
	Tributary delta formation	Tributary delta formation occurs where larger tributaries drop sediment at the confluence of the main stem rivers that cannot be transported away by the river.

Ecological Consideration	Criteria	Definition
	Wind-wave erosion of islands	Wind-wave erosion of islands occurs where former floodplain ridges remaining exposed above the surface of the regulated river elevation were eroded away over time. Large open water impounded areas remained after the islands disappeared.
	Island dissection	Island dissection refers to the process where erosion cuts through an island mass to create two or more separate islands.
	Island formation	Island formation refers to the process of sediment accumulation above the normal river stage. In natural channels, log jams, mass sediment movement, and over bank sedimentation can cause island formation. In the modified river, training structures and dredging can also promote island formation.
	Island migration	Island migration refers to the movement of islands in the downstream direction.
	Topographic diversity	Topographic diversity is the variation in relief in terrestrial floodplain areas, ridge and swale topography. Natural levees build ridges and overbank flow can scour channels and depressions.
	Upland watershed dynamics	Upland watershed dynamics affecting mainstem habitats include the delivery of water and materials. While a natural process, the rates of delivery and volume of materials has changed, usually increased, over time. Important watershed dynamics are runoff rates and volumes, sediment, macronutrients, and contaminants.
	Water clarity	Water clarity is an important determinant of aquatic plant growth and also affects predator-prey interactions among organisms. Water clarity is affected by algae in the water column and suspended sediment. In many places sediment resuspension can exceed the concentration of sediment delivered from upstream. There may also be seasonal fluxes in water clarity.
	Suspended sediment	Suspended sediment is inorganic fine silt material floating in the water column. Suspended sediment blocks light through the water column and inhibits plant growth.
	Nutrients	Nutrients are natural elements required for plant growth. The macronutrients nitrogen and phosphorus are prominent in most ecosystems, but a variety of trace nutrients are also important.
	Chlorophyll	Chlorophyll is the photosynthetic pigment found in plants and algae. In aquatic systems chlorophyll is frequently measured as a surrogate of algal quantities or production.
	Oxygen	Dissolved oxygen concentration is an important determinant of aquatic habitat quality for many aquatic organisms. Minimum concentrations desired for fish habitat is typically greater than 4 mg/L, although some fishes and other organisms may require higher concentrations.
	Natural toxicity (e.g., ammonia)	There are many chemical forms of nutrients that can form under different conditions of oxygen, temperature, or microbial activity. Nitrogen in particular can rapidly form toxic ammonia compounds under certain conditions.
	Contaminants	Contaminants is a very general term for a variety of man made or introduced compounds that are toxic to aquatic plants and animals. Discharge of industrial contaminants has been successfully regulated, largely, and most issues now relate to latent pollution from the past. Many agrichemicals, like herbicides and pesticides, can also be considered contaminants.
	Temperature	Water temperature is an important consideration for fish overwintering habitat primarily. It is desirable to create or maintain thermal stratification in deeper, non-flowing habitats where warm (4oC), dense water settles to the bottom and cold, light water rises to the surface where it may freeze. Temperature variation also affects the growth of fish and other ectotherms year round. Thus, providing diverse thermal habitat may enhance species diversity.

Ecological Consideration	Criteria	Definition
Habitat		
	Diversity	The number of different kinds (species, genera, etc.) of organisms or geomorphic features (ridge, swale, channel, backwater, etc.). Habitat diversity is a measure of the types of geomorphic features and habitats, their size, and their relative abundance in a defined area . Biodiversity-is the variability within and among living organisms and the systems they inhabit
	Quality	The desired mix and productivity of habitat/landcover types.
	Abundance	Habitat abundance is the spatial quantity (i.e. acres) of various habitat types or the number of different organisms of an individual species
	Distribution	Habitat distribution is the spatial arrangement of various habitat types. The spatial property of a resource being scattered over an area
	Patch size	A particular habitat unit with identifiable boundaries which differs from its surroundings in one or more ways. These can be a function of vegetative composition, structure, age or some combination of the three.
	Corridor	A defined tract of land, usually linear, through which a species must travel to reach habitat suitable for reproduction and other life-sustaining needs.
Ecosystem		
	Primary production	Primary production is the measure of plant and algal conversion of sunlight energy to plant material that can then be transferred up the food chain.
	Carbon sequestration	Carbon sequestration is conversion of inorganic and organic carbon to plant energy and its subsequent up through the food chain.
	Proximity of critical habitat	Proximity of critical habitat refers to specific habitat requirements of individual species. These requirements may be seasonal and be more critical during stressful environmental conditions such as winter or flooding. Migratory species may also have specific habitat requirements that must be appropriately spaced along migratory routes. Specific distances between critical habitats will vary among species.
	Proximity of life requisite habitat	Proximity of requisite species is the consideration of the ability of an animal to meet all of its life history requirements (e.g., growth, reproduction, and survival) within the area an animal is able to move.
	Ecosystem engineers (e.g., beavers, carp, etc.)	Many animals can shape the habitat they inhabit. Beavers are a prominent example of an organism that forms habitat through dam construction, but common carp are a less obvious example of a creature that can degrade habitat by stirring sediment with its feeding and spawning activities which can resuspend sediment and block light availability to plants.
	Nutrient transformations and cycling	Nitrogen and phosphorus are important elements that occur in different forms under different environmental conditions. These various forms can be transformed and used by plants or converted to inert forms (e.g., nitrogen gas through denitrification).
	Biogeochemical processes	Biogeochemical processes include the variety of energy transformations that occur as plants sequester nutrients and convert them into forms consumed by animals that convert the plant energy to animal growth. There are also complex decomposition pathways that break down dead plant and animal matter into elemental nutrients. In a very detailed view, biogeochemical processes also include issues of genetic diversity and gene transfer.
	Disturbance	Natural disturbances include geomorphic, climactic, physical/chemical and biological processes that form the physical template of habitats in the landscape, affecting the distribution and abundance of life forms. Disturbances can be described in terms of their frequency, timing, duration, severity, spatial extent of effect, and predictability. Disturbances at intermediate frequencies tend to enhance biotic diversity.

Ecological Consideration	Criteria	Definition
Biota		
	Terrestrial Plant Communities	Terrestrial plant community is a very broad classification to generalize the relative location or spatial emphasis of restoration projects. Projects frequently address aquatic and terrestrial objectives.
	Aquatic Plant Communities	Aquatic plant community is a very broad classification to generalize the relative location or spatial emphasis of restoration projects. Projects frequently address aquatic and terrestrial objectives.
	Migratory Waterbirds	Migratory waterbirds include ducks, geese, swans, large wading birds, shorebirds, gulls, and terns. Some species have strict habitat requirements, others are generalists that are used to establish ecological design criteria.
	Neotropical Migrants	A variety of songbirds that spend the winter months in Central and South America and summers in North America
	Terrestrial and Semi-Aquatic Resident Wildlife	Furbearers are closely associated with river habitats while larger mammals may only use river habitats for part of their needs.
	Amphibians and Reptiles	Amphibians and reptiles occupy many habitats and may be a consideration in many project features.
	Backwater Fishes	Backwater fishes is a general reference to fish that prefer low flow environments found in off channel area. Sunfish and bass are generalists used to establish ecological design criteria. Also, many river-dwelling species have life stages dependent on these backwater environments.
	Riverine Fishes	Riverine fishes is a general reference to fishes that are adapted to flowing channel habitats. Sturgeon, walleye, smallmouth bass, and catfish are common targets of channel habitat restoration.
	Freshwater Mussels	UMRS freshwater mussels are a unique ecological resource that has been highly impacted from multiple causes. Host fish migration is a concern of the fish passage investigations.
	Aquatic Macroinvertebrates	Restoration activities commonly manipulate the substrate that aquatic macroinvertebrates live in and on. Promoting aquatic vegetation creates a diverse community of macroinvertebrates and plankton. Sediment and flow manipulations can remove or compact silty sediments to improve conditions for burrowing mayflies and fingernail clams. Rock substrates in swift flowing habitats frequently support large concentrations of caddisflies and other critters.
	DNA/Biodiversity/Genetic Vigor	Biodiversity and genetic integrity includes the assessment and conservation of species and consideration for the maintenance of local stocks or stains of some plants and animals. The concerns are important to all populations, but especially to stressed populations. Plantings may be obtained from local nurseries or fish may be spawned from brood stock collected at a site. Removal of barriers to migration and maintenance of requisite habitats are important management actions.
	Exotic species	Exotic species are non-natives that sometimes achieve nuisance populations that may impact resident species. Some native species may also achieve nuisance levels.
	Disease/parasites	Disease and parasites may affect individuals or populations in extreme cases. While preventing/ameliorating local outbreaks are not typically a restoration objective, widespread impacts such as the forest changes caused by pathogens such as Dutch-elm disease and the introduction/transmission of pathogens via human-induced stocking or manipulation of organisms (e.g., whirling disease) must be avoided

Ecological Consideration	Criteria	Definition
	Water stage regulation	Water stage regulation is an action using structures to impede the downstream flow of water, thus in creasing water depth upstream from the control structure. In the UMRS, 37 dams impound water to create 9-foot deep navigable waterways. A variety of control structures including culverts, gates, and stoplogs are used to maintain water levels in backwater independent of the river stage.
	Floodwater distribution	Floodwater distribution is the spatial coverage of river waters during high flow events. In many parts of the UMRS, floodwater distribution is restricted by levees.
	Flow distribution	Flow distribution refers to the movement of water through channels and backwaters at "normal" river stages. There are many natural features directing flow, but the regulated river has thousands of rock structures (wing dams, closing dams, etc.) designed and placed to direct river flow to preferred locations.
	Water retention time	Water retention time usually refers to how long water stays in off channel habitats. Generally, residence time is shorter closer to the channel and longer as areas are more isolated from the channel. Completely isolated backwaters have 100% residence times, other isolated lakes may be overtopped once or more times per year, connected lakes may have minimal exchange at the mouth, but get flushed when overtopped, and others may have continuous low flow year round.
	Isolation/desiccation	Isolation/desiccation is a result of river stages falling below the elevation of backwater connecting channels. As river and groundwater levels drop below the backwater bottom water can evaporate leaving the site exposed to dry in the sun and wind.
	Wind Fetch	Wind fetch is the distance wind blows unobstructed across open water areas. Long wind fetch can result in significant wave action.
	Water table/Groundwater	The water table or groundwater is water settling in or slowly moving through soils or rock formations. In the river environment, groundwater levels can fluctuate with river stages.
	Minimum habitat requirements	Does the Project supply the minimum habitat feature for an endangered, threatened, or species of special concern or a species of commercial or recreational importance
	Temporal considerations/dependencies	Is this project linked to another project or feature that needs to be done in a sequence before benefits are achieved
	Spatial considerations/dependencies	How much of the available desired habitat is present in the proposed project area. (How critical is this project at the pool and reach level)
	Bioenergetics	How will the proposed project increase the availability of photosynthetically derived energy (and also allocthonous sources) to the biota (i.e., positively increase biological production)
	Functional diversity	Will the project function (rehabilitate) in the area proposed. (Project should score low if putting in a backwater where none has ever been.)
	Structural diversity	Will the project cause the UMRS to more realistically mimic the physical and biological template of an unaltered large river. (Again, project should score low if structure or river hydrology or species composition, etc. are not as expected; e.g., stocking in non-native species)

Appendix C
Environmental Models

Note: The use of environmental models is discussed and described based on the experience of the Science Panel and RST. Environmental models are typically complicated procedures with specific equations and computer programs. It is impossible to describe them in this document, but readers should have access to information that is available. Many environmental model web pages were visited to obtain their short descriptions and web links.

ENVIRONMENTAL MODELS

ADDAMS models. The versions of the models in this appendix are a part of the Automated Dredging and Disposal Alternatives Management System (ADDAMS) (Schroeder and Palermo, 1990) and can be run on a personal computer (PC). ADDAMS is an interactive computer-based design and analysis system in the field of dredged-material management. The general goal of the ADDAMS is to provide state-of-the-art computer-based tools that will increase the accuracy, reliability, and cost-effectiveness of dredged-material management activities in a timely manner.

ADH (with nutrient library). ADH (Adaptive Hydraulics model) contains solvers for groundwater and two-dimensional shallow water flows. It is capable of refining or coarsening the grid based on error estimates during flow calculations.
(source: http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-ix-4.pdf)

ANNAGNPS. This paper describes the capabilities of the Annualized Agricultural Non-Point Source model, AnnAGNPS. This evaluation discusses model capabilities, appropriate applications, sensitivity, testing, and availability. AnnAGNPS is a continuous-simulation, multi-event modification of single-event model AGNPS with improved technology and the addition of new features. The model can be used to predict non-point source pollutant loadings from agricultural watersheds. It is a tool for comparing the effects of implementing various conservation alternatives within the watershed. Cropping systems, fertilizer application rates, water and dissolved nutrients from point sources, sediment with attached chemicals from gullies, soluble nutrient contributions from feedlots, and the effect of terraced fields can be modeled. AnnAGNPS was first released in February 1998. AnnAGNPS includes all the features that were in the original AGNPS plus pesticides, source accounting, settling of sediments due to in-stream impoundments, and the Revised Universal Soil Loss Equation. Several tools have been developed to facilitate development of input data files and for analysis of output data.
(source: http://www3.bae.ncsu.edu/Regional-Bulletins/Modeling-Bulletin/bosch-annagnps-bulletin-manuscript.html)

AQUATOX is a simulation model for aquatic systems. AQUATOX predicts the fate of various pollutants, such as nutrients and organic chemicals, and their effects on the ecosystem, including fish, invertebrates, and aquatic plants. This model is a valuable tool for ecologists, biologists, water quality modelers, and anyone involved in performing ecological risk assessments for aquatic ecosystems. (source: http://www.epa.gov/ost/models/aquatox/)

CASM is a flexible, bioenergetics-based modeling framework that allows the user to specify multiple populations of aquatic producers and consumers. CASM permits the user to define food web structure, define trophic interactions, and estimate bioenergetics parameters for modeled producers and consumers. The model simulates the daily production dynamics of modeled populations in relation to user-specified values for water depth, current velocity, light intensity, water temperature, and dissolved nutrients (N, P, Si). This model also simulates decomposition processes, dissolved oxygen concentration, and nutrient cycling.

CONCEPTS (ARS). The National Sedimentation Laboratory has developed the CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) computer model to simulate the evolution of incised streams and to evaluate the long-term impact of rehabilitation measures to stabilize stream systems and reduce sediment yield. CONCEPTS simulates unsteady, one-dimensional flow, graded sediment transport, and bank-erosion processes in stream corridors. It can predict the dynamic response of flow and sediment transport to instream hydraulic structures. It computes channel evolution by tracking bed elevation changes and channel widening. The bank erosion module accounts for basal scour and mass wasting of unstable cohesive banks. CONCEPTS simulates transport of cohesive and cohesionless sediments, both in suspension and on the bed, and selectively by size classes. CONCEPTS also includes channel boundary roughness varying along a cross section, for example due to varying vegetation patterns. (http://www.ars.usda.gov/Research/docs.htm?docid=5453)

CEQUAL-W2 is a two-dimensional, laterally averaged, finite difference hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. The model can be applied to rivers, lakes, reservoirs, and estuaries. Branched networks can be modeled.

The model accommodates variable grid spacing (segment lengths and layer thicknesses) so that greater resolution in the grid can be specified where needed. The model equations are based on the hydrostatic approximation (negligible vertical accelerations). Eddy coefficients are used to model turbulence. The hydrodynamic time step is calculated internally as the maximum allowable time step that ensures numerical stability. A third-order accurate (QUICKEST) advection scheme reduces numerical diffusion.

The water quality portion of the model includes the major processes of eutrophication kinetics and a single algal compartment. The bottom sediment compartment stores settled particles, releases nutrients to the water column, and exerts sediment oxygen demand based on user-supplied fluxes; a full sediment diagenesis model is under development.
(source: http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home?selection=cequalw2)

Delft 3-D Sed

Delft3D is the world's most advanced 2D/3D integrated modelling environment for:

- Hydrodynamics
- Waves
- Sediment transport
- Morphology
- Water quality
- Particle tracking for water quality
- Ecology

Delft3D also has support tools for:

- Visualisation: Delft3D-GPP
- Grid generator: Delft3D-RGFGRID
- Bathymetry generator: Delft3D-QUICKIN

(Source: http://www.wldelft.nl/soft/d3d/intro/index.html)

Delft3d
DHI – Delft software with GIS
DHI – Mike11
DHI – Mike11 with GIS

Ecological DYnamics Simulation (EDYS)

Background
Ecosystem management of public lands is hindered by a lack of predictive tools that assess management alternatives under a wide variety of land/water use and disturbance scenarios. This is especially problematic on lands subjected to multiple land use practices, stakeholders, and regulatory constraints. Tools that adequately accommodate the process complexities of ecological dynamics at various spatial and temporal scales would be of great utility to decision makers. The **(EDYS)** system was developed to assist managers in selecting defensible strategies to best meet difficult management objectives, given complex regulatory constraints, and variable climatic and disturbance scenarios.

EDYS Capabilities
EDYS has been applied in a wide variety of land/water management scenarios, including: military training, recreational activities, grazing, natural and prescribed burns, fire suppression, road/trail building and closure, invasive plants inventory and eradication, drought assessment, water quality/quantity, reclamation, restoration and revegetation, land cover design, and slope stability.

EDYS is designed to mechanistically simulate complex ecological dynamics across spatial scales ranging from plots (square meters) to landscape and watershed (square kilometers) levels. Modules include climatic simulators, hydrology, soil profile, nutrient and contaminant cycles, plant community dynamics, herbivory, animal dynamics, management activities, and natural/anthropogenic disturbances. Designation of scenarios and management alternatives for each simulation run is conducted within a Microsoft Windows user interface. Outputs include graphical displays in this interface, as well as extensive tabular files for all ecosystem components.

Typical inputs to each EDYS application include spatial data (e.g., grid-based GIS data sets), historical climatic data, soil profile parameters, plant/animal parameters, management practices, and specifications for user-defined endpoint data. "First pass" calibration of the model is facilitated by the EDYS Database, which contains soil, plant, management, and disturbance parameters compiled from the ecological literature and ongoing EDYS applications nationwide and overseas.
(source: http://el.erdc.usace.army.mil/nrrdc/pdfs/edys.pdf)

Elly Best SAV Model

Fish Bioenergetics Models (Wisconsin)

FLO2DH. **Flo2DH,** Release 3, is a two-dimensional finite element surface water computer program that can compute the direction of flow and water surface elevation in a horizontal plane. Flo2DH has the ability to model hydraulic structures commonly used by hydraulic engineers. (source: http://www.waterengr.com/WRCSH&H.html#Flo2DH)

Flow3D. Flow Science, a leading provider of computational fluid dynamics (CFD) solutions for complex fluid modeling problems for a wide range of industrial applications. Flow Science's flagship software, ***FLOW-3D***, enables highly accurate simulations of free surface flows using **TruVOF**, the original and true form of the Volume-of-Fluid technique. The **FAVOR**™ method, which is unique to ***FLOW-3D***, enhances both the ease of use and the accuracy of flow simulations.

New* General Moving Objects Model.** With Version 9.0, ***FLOW-3D now offers users to model rigid body dynamics with six-degrees-of-freedom fully coupled with fluid flow!

FLOW-3D*'s Applications.** ***FLOW-3D can be used to tackle the most difficult of fluid dynamics problems in a broad array of industrial and research applications. Follow the links below for a sampling of what you can accomplish with ***FLOW-3D.***

Aerospace	Inkjets
Casting	Maritime
Coating	MEMS
Consumer Products	Water & Environmental

(source: http://www.flow3d.com/)

FLUENT. Fluent is the world's largest provider of computational fluid dynamics (CFD) software and consulting services. Our software is used for simulation, visualization, and analysis of fluid flow, heat and mass transfer, and chemical reactions. It is a vital part of the computer-aided engineering (CAE) process for companies around the world, and is deployed in nearly every manufacturing industry. (source: http://www.fluent.com/)

FLUX. Program allows estimation of tributary mass discharges (loadings) from sample concentration data and continuous (e.g., daily) flow records. Five estimation methods are available and potential errors in estimates are quantified.
(source: http://el.erdc.usace.army.mil/elmodels/emiinfo.html)

Forest Succession Models
The literature on vegetation succession is very extensive, yet there are no models for Upper Mississippi River vegetation succession. Klimas et al. 1981 developed a forest successional model for the Lower Mississippi River which should also be done for the Upper Mississippi River.

Klimas, C.V., C.O. Martin, and J.W. Teaford. 1981. I*mpacts of Flooding Regime Modification on Wildlife Habitats of Bottomland Hardwood Forests in the Lower Mississippi Valley*. U.S. Army Engr. Waterway Expt. Stn., Rep. # EL-81-13. 200 pp. I

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Shugart, H.H. and D.C. West. 1977. *Development of an Appalachian Deciduous Forest Succession Model and its application to assessment of the impact of the chestnut blight.* J. Environ. Manage., 5: 161-179

H.H. Shugart 1984. *A Theory of Forest Dynamics: The Ecological Implications of Forest Succession Models* (1984) Springer-Verlag, New York. 278 pp.

Shao, G., S. Zhao and H.H. Shugart. 1996. *Forest Dynamics Modeling - Preliminary Explanations of Optimizing Management of Korean Pine Forests* [in Chinese]. Chinese Forestry Publishing House, Beijing. 159 pp.

Shugart, H.H. 1998. Terrestrial Ecosystems in Changing Environments. Cambridge University Press, Cambridge. 537 pp.

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GSSHA. Gridded Surface/Subsurface Hydrologic Analysis. Spatially distributed hydrologic model that incorporates land use and soil type information

Backwater Suitability Models - USGS. We used the GIS to calculate a host of basic morphometric characteristics (e.g., total perimeter, total surface area, shoreline development, number of connections to channel, percent of perimeter represented by channel) for every backwater in Pool 8. We then used a sampling design that divided the backwaters into three sampling strata based on area and connectivity to channels, and randomly selected a total of 51 backwaters for field sampling. In February 1997, we intensively searched each randomly selected backwater for suitable overwintering conditions defined by water temperature greater than 0.5° C, current velocity less than 0.01 m/sec, dissolved oxygen greater than 2.0 mg/L, and water depth greater than 30 cm. Based on our field measurements, we then classified each water body in our sample as "suitable" if any location within the backwater was found that met our habitat criteria and "unsuitable" if no such site was found. (source: http://www.umesc.usgs.gov/reports_publications/psrs/psr_1998_01.html)

Gap Models

- Gap Analysis is a scientific means for assessing to what extent native animal and plant species are being protected. It can be done at a state, local, regional, or national level.

- The goal of Gap Analysis is to keep common species common by identifying those species and plant communities that are not adequately represented in existing conservation lands. Common species are those not threatened with extinction. By identifying their habitats, Gap Analysis gives land managers, planners, scientists, and policy makers the information they need to make better-informed decisions when identifying priority areas for conservation

- Gap Analysis came out of the realization that a species-by-species approach to conservation is not effective because it does not address the continual loss and fragmentation of natural landscapes. Only by protecting regions already rich in habitat, can we adequately protect the animal species that inhabit them.

(source: http://www.gap.uidaho.edu/)

Geomorphic/River Engineering Approaches
See Micro-models below

GIS Landscape Models – USGS

HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities.

The HEC-RAS system will ultimately contain three one-dimensional hydraulic analysis components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; and (3) movable boundary sediment transport computations.

Currently steady and unsteady flow are available and sediment transport is under development. A key element is that all three components will use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed, including bridge scour computations, uniform flow computations, stable channel design, and sediment transport capacity.

The current version of HEC-RAS supports steady and unsteady flow water surface profile calculations. New features and additional capabilities will be added in future releases.
(source: http://www.hec.usace.army.mil/software/hec-ras/hecras-philosophy.html)

HIVEL2D is a free-surface, depth-averaged, two-dimensional finite element model designed specifically to simulate flow in typical high-velocity channels.
(source: http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=SOFTWARE;6)

ICM. The CE-QUAL-ICM water quality model was initially developed as one component of a model package employed to study eutrophication processes in Chesapeake Bay. Subsequent to employment in the Bay study, the model code was generalized and minor corrections and improvements were installed.

ICM stands for "integrated compartment model," which is analogous to the finite volume numerical method. The model computes constituent concentrations resulting from transport and transformations in well-mixed cells that can be arranged in arbitrary one-, two-, or three-dimensional configurations. Thus, the model employs an unstructured grid system.

The model computes and reports concentrations, mass transport, kinetics transformations, and mass balances. Features to aid debugging include the ability to activate or deactivate model features, diagnostic output, and volumetric and mass balances. Computations can be restarted following interruption due to computer failure or similar circumstances. CE-QUAL-ICM is coded in ANSI Standard FORTRAN F77. The model operates on a variety of platforms including 486 PC, Silicon Graphics, and Hewlett Packard workstations. A multi-processor version is available but not generally released. The user must provide processors that prepare input files and process output for presentation.

The model does not compute hydrodynamics. Flows, diffusion coefficients, and volumes must be specified externally and read into the model. For simple configurations, flows may be entered through an ASCII input file. For more advanced applications, hydrodynamics are usually obtained from a hydrodynamics model such as the CH3D-WES model. The unstructured, finite volume structure of the model was selected to facilitate linkage to a variety of hydrodynamic models.

There are two distinctly different development pathways to ICM: a eutrophication model (ICM), and an organic chemical model (ICM/TOXI). The release version of the eutrophication model computes 22 state variables including physical properties; multiple forms of algae, carbon, nitrogen, phosphorus, and silica; and dissolved oxygen. Recently, two size classes of zooplankton, two benthos compartments (deposit feeders and filter feeders), submerged aquatic vegetation (roots and shoots biomass), epiphytes, and benthic algae were added, although this version of the code is not generally released to the public. Each state variable may be individually activated or deactivated. One significant feature of ICM, eutrophication version, is a diagenetic sediment sub-model. The sub-model interactively predicts sediment-water oxygen and nutrient fluxes. Alternatively, these fluxes may be specified based on observations.
(source: http://el.erdc.usace.army.mil/elmodels/icminfo.html)

IHA. The Indicators of Hydrologic Alteration program was developed by scientists at the Nature Conservancy to facilitate hydrologic analysis in an ecologically-meaningful manner. This software program assesses 67 ecologically-relevant statistics derived from daily hydrologic data. For instance, the IHA software can calculate the timing and maximum flow of each year’s largest flood or lowest flows, then calculates the mean and variance of these values over some period of time. Comparative analysis can then help statistically describe how these patterns have changed for a particular river or lake, due to abrupt impacts such as dam construction, or more gradual trends associated with land- and water-use changes.
(source: http://www.freshwaters.org/tools/)

IIHR 3-D Sediment Transport Models. IIHR has focused on a high fidelity, science-based modeling foundation based on fully three-dimensional computational fluid dynamics (CFD) modeling approaches developed for the mechanical and aerospace industries and transferred to river engineering applications by IIHR researchers. These models are based on either Reynolds-averaged Navier Stokes (RANS) formulations with turbulence closure equations or on Large Eddy Simulations which capture the time dependencies of fluid motion and require turbulence closure equations for only the sub-grid scale turbulence. Although computationally more costly than 1D, 2D or 3D hydrostatic models, these fully three-dimensional model are first-principles based models that can more accurately replicate the flow physics. Such models can be applied from project to pool scales depending on the geometric complexity.

High resolution, high fidelity numerical modeling could provide the following:

- A descriptive three-dimensional fluid environment to link with agent-based or individual-based ecological models. Examples such as the mussel dynamics model that predictive biomass and individual production of mussels for all life stages and the numerical fish surrogate have been developed.
- Insight into biogeochemical fluxes between backwater areas and main channel areas and effect of changing hydrographs during flood events.
- Evaluation of primary and secondary production based on hydraulic exchange rates
- Local scour predictions and multiple size class sediment transport

(source: http://www.iihr.uiowa.edu/)

LES modeling . Large eddy simulation (LES) is one of the most successful techniques in the numerical simulation of turbulent flows. Unlike direct numerical simulation (DNS), which tries to capture all the scales in the flow, LES aims at resolving only the large-scale flow features as defined by a filtering operation. One of the challenges in LES is modeling the subgrid-scale stresses, and a wide variety of models have been developed for this purpose.

Iliescu and Fischer applied the rational LES model (RLES) to numerical simulations of incompressible channel flows at Reynolds numbers based on the friction velocity and the channel half-width $Re_\tau = 180$ and $Re_\tau = 395$. RLES is an approximate deconvolution model based on a rational (Padé) approximation to the Fourier transform of the Gaussian filter and is proposed as an alternative to the gradient model. The authors compared the RLES results with those from the gradient model, the Smagorinsky model, and a coarse DNS with no LES model; all of these were benchmarked against the fine DNS calculations of Moser et al.

The RLES model yielded the best results for the $Re_\tau = 180$ case and showed much better numerical stability than the gradient model (figure 2). For the $Re_\tau = 395$ case, the RLES model and the gradient model yielded comparable results, and the Smagorinsky model performed the best. The next step will be to develop a mixed model, consisting of RLES supplemented by a Smagorinsky model.
(source: http://www.nersc.gov/news/annual_reports/annrep02/47-channel-flows.html)

Micro Models

Micro Modeling is extremely small scale, physical sediment transport modeling. Engineers are now able to replicate the mechanics of an actual river or stream on an area the size of a normal table top.

With the development of the micro scale technology, engineers can now use these models to solve complex sedimentation problems quickly and cost effectively. Using Micro Modeling, an innovative engineering or biological design can be model tested, evaluated, and constructed in the actual river or stream within a few short months. Such progressive, high speed design and construction is unprecedented in the field of river and sediment transport engineering!

The theory of why sediment transport modeling works on a micro scale follows the same basic principle applied to large modeling efforts. It is a fact that small streams behave very similar to large rivers. A river, no matter how large or small, is a body of flowing water. The mechanics of moving water and sediment remain similar, whether it's a trickle of water, a backyard creek, or the Mississippi River. Therefore, a small stream can actually be described as a model of a larger river.

NavFSH
Conditional entrainment mortality model
• Population-level extrapolations
- Equivalent Adults Lost
- Recruitment Forgone
- Production Forgone

NavLEM
Conditional entrainment mortality model
• Population-level extrapolations
- Equivalent Adults Lost
- Recruitment Forgone
- Production Forgone

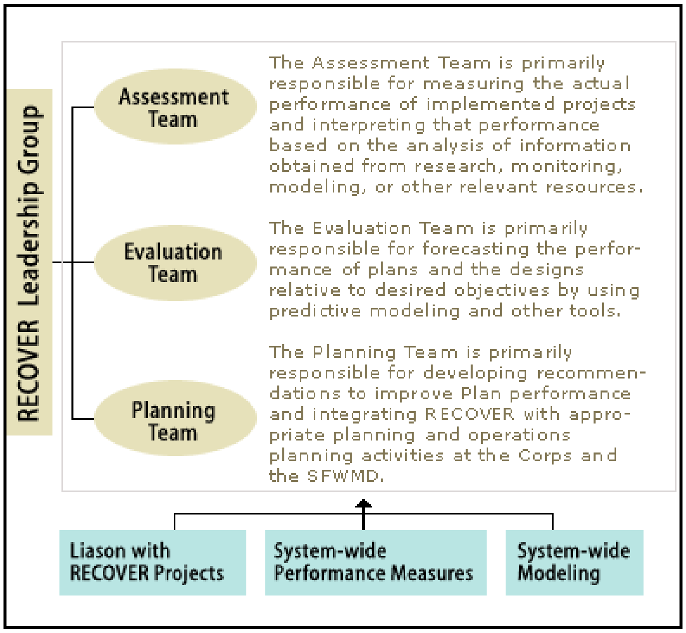
NavSAV
Spatial Characterization of Incremental
Traffic Impacts on SAV Growth in Pool 8

Other CHL Models - http://chl.erdc.usace.army.mil/

RECOVER. RECOVER is an arm of the Comprehensive Plan (CERP) responsible for linking science and the tools of science to a set of system-wide planning, evaluation and assessment tasks. Our objectives are to:

- Evaluate and assess Comprehensive Plan performance
- Refine and improve the plan during the implementation period, and
- Ensure that a system-wide perspective is maintained throughout the restoration program

RECOVER is composed of three technical teams that align with its mission areas.



(Source: http://www.evergladesplan.org/pm/recover/recover.cfm)

RMA-2. RMA2 is a two dimensional depth averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two dimensional flow fields. RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's or Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady state (dynamic) problems can be analyzed.
(Source: http://chl.wes.army.mil/software/tabs/rma2.htp)

SED2D

SED2D

Formerly STUDH, a two-dimensional numerical model for depth-averaged transport of cohesive or a representative grain size of noncohesive sediments and their deposition, erosion, and formation of bed deposits. (Source: http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software!17)

SECASM. Spatially Explicit Comprehensive Aquatic Systems Model is a variant of the CASM model described above. SECASM will expand outside of the river banks to incorporate terrestrial plant community dynamics responding to changes in the river system.

SIAM - System Impact Assessment Model. The USGS Fort Collins Science Center has recently completed Version 4 of the Systems Impact Assessment Model (SIAM) for the Klamath River. SIAM is an integrated set of models used to address significant interrelationships among selected physical (temperature, microhabitat), chemical (dissolved oxygen, water temperature) and biological variables (young-of-year chinook salmon production), and stream flow. SIAM has been developed for the Lower Klamath River between Upper Klamath Lake, Oregon, and its outlet at the ocean in northern California, and covers a period from 1961 to near the present. These models and data have been assembled to evaluate and compare potential impacts of alternative water management alternatives from an ecological perspective.

SIAM's goal is to further the process of reaching a consensus on the management of water resources in order to stabilize and restore riverine ecosystems. SIAM should be used in the context of the Instream Flow Incremental Methodology (IFIM). As such, water management implies direct or indirect control of the quality, magnitude, duration, frequency, timing, or rate of change in river flows under man's influence. SIAM is a planning and management model rather than a research or operations model. Management models integrate the best available knowledge to provide managers with the predicted results of potential actions -- a what-if model. SIAM may be used in a planning mode by portraying the simulated effects of actions against the long-term historical backdrop. Planning models are descriptive, fostering the development of robust and non-arbitrary policies; in contrast, operational models are prescriptive and generally used to fine tune near-future actions.

SIAM starts with a water quantity model, MODSIM, to predict river flows and track reservoir volumes in the Klamath River system downstream from the U.S. Bureau of Reclamation's Klamath Project and through the reservoir complex managed by PacifiCorp. MODSIM employs a prioritization scheme to model flows throughout this system under different water management alternatives consisting of reservoir operating rules and constraints, instream flow requirements, and out-of-stream demands.

Flows simulated by MODSIM are passed to a water quality model, HEC-5Q, to predict selected water quality constituents throughout the river. For the Klamath River, the important constituents simulated are water temperature and dissolved oxygen. Fish production is dependent on micro and macro aquatic habitat, as well as the number of adult spawners. SIAM employs a fish production model, SALMOD, to predict the relative number and weight of juvenile anadromous salmonids successfully exiting the study area. It also identifies the relative magnitude of various sources of mortality (including water temperature, movement, and nesting superimposition) throughout the early life history of the species under consideration.

Collectively, SIAM's output metrics are used to characterize ecosystem health. Though not represented by a single numeric quantity, ecosystem health is embodied in the output by tallying the number of occurrences of the various metrics falling outside of user-prescribed bounds, and the physical extent of those deviations. For example, dissolved oxygen falling below 5.0 mg/l on a daily basis would be flagged as unacceptable. One of SIAM's outputs for ecosystem health is a set of "red flag" displays that capture the encroachment of standards through time and space.

Binding the models and data is the user interface for SIAM which tracks the options that the user wants to simulate, passes data and simulation results as necessary to the appropriate models, and summarizes the output for convenient display. The user interface is responsible for the almost endless bookkeeping that is required to link models together that may work off of different spatial and temporal scales, different input and output units, and different computer file formats.

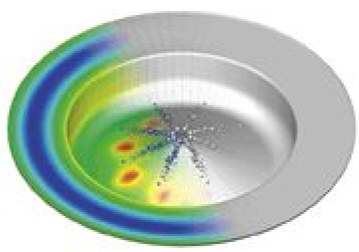
Version 4 (October 2005) has been enhanced in several ways. Fish production data files have been parameterized for the Klamath River (though this sub-model has not been fully calibrated or validated). Bugs have been fixed from Version 3, and Help files and documentation have been thoroughly updated.
(source: http://www.fort.usgs.gov/products/software/siam/siam.asp)

SPARROW (USGS) - SPAtially Referenced Regressions On Watershed Attributes

SPARROW relates in-stream water-quality measurements to spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and stream transport.

The model empirically estimates the origin and fate of contaminants in streams, and quantifies uncertainties in these estimates based on model coefficient error and unexplained variability in the observed data.
(source: http://water.usgs.gov/nawqa/sparrow/)

StarCD - Computational Fluid Dynamics



Computational Fluid Dynamics (CFD) seems to be undergoing an increase in popularity of late. Many of the traditional FEA-based developers have recently started to incorporate some form of CFD code into their structural analysis tools, often through licensing of another's code or through their own in-house developments. But is this an area of analysis that has traditionally been quite separate from FEA, so one might wonder whether a standalone system, developed by specialists, may be more useful, particularly if you want to delve deeper into its use and more advanced functions - in short, the age old question of whether to deal with the monkey or the organ grinder? Thankfully, StarCD is developed by The CD Adaptco Group and with a 25-year history in the field, it definitely qualifies as the latter.

The release of its StarCD system under review takes a SolidWorks-integrated form but the level of that integration may be less than many SolidWorks users would be accustomed to. Once you have arrived at the point in your product's development where you need to perform CFD analysis, you need to create a separate model (of either the part or assembly), which can be used. Unlike many FEA systems, the model required by StarCD is quite different and the ultimate goal is the creation of the geometry of the internal section of your product. Taking the example of a valve, you need to create the cavity within the valve. Luckily, this is quite easy to accomplish in SolidWorks using the cavity creation tools (which are more commonly used for mould design). Before carrying out the final 'Insert Cavity' operation to create the fluid model, you need to close of any gaps in the model (such as inlets and outlets etc) within simple solid extrusion.
(source: http://www.cadserver.co.uk/common/viewer/archive/2002/Feb/5/feature27.phtm)

SWAT. SWAT is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds.
(source: http://www.brc.tamus.edu/swat/index.html)

U²RANS. U²RANS is a three-dimensional (3D) Unsteady and Unstructured Reynolds Averaged Navier-Stokes solver. The code was developed by Dr. Yong Lai while he was appointed as the senior research staff and adjunct associate professor at the Iowa Institute of Hydraulic Research, University of Iowa. The model is highly accurate, well verified and validated, and has been successfully applied to many research and engineering projects.

Briefly, U²RANS is a comprehensive general-purpose model. Three-dimensional hydraulic flow models such as U²RANS are accurate and mature tools, which have been routinely used to address many hydraulic engineering problems such as:

- flow hydrodynamics in pools and river reaches upstream of hydropower dams;
- detailed flow characteristics around hydraulic structures;
- hydraulic impact of different project alternatives;
- fish passage facility design and evaluation;
- thermal mixing zone determination;
- design optimization, reservoir/lake stratification, selective cold water withdrawal, etc.

The main limitation is that they are usually applied to a river reach less than five miles in length due to their heavy requirement for computer power.

U²RANS uses current state-of-the-art, unstructured CFD technology, unifies multi-block structured mesh (quad or hex) and unstructured mesh (quad, triangle, tet, hex, wedge, pyramid, or hybrid) elements into a single platform, and combines 2D and 3D solvers in a common framework. A User's Manual is available, which provides a more detailed description about the general features and capabilities.

Processes Modeled:

- Accurate solution of full three-dimensional water flows with complex geometry
- 3D effects, such as secondary flows at the meandering bends and point bars, vortex/eddy generation due to hydraulic structures, are accurately captured
- Water temperature transport is simulated using the energy conservation equation

Processes Ignored

- Sediment transport is not modeled
- **Fixed bed geometry is assumed**

Model Input

- Detailed bathymetric data and hydraulic structure geometric data
- River discharge and water surface elevation at the downstream boundary

Model Output

- 3D spatial distribution of velocity magnitude and flow direction
- Location and strength of flow eddies and vortices
- Secondary flows due to meandering
- Bed shear stresses
- Water surface elevation distribution and backwater effect

Potential Use of Output Results

- Evaluate erosion/deposition potential at the point bar due to secondary flows
- Assess scouring potential due to hydraulic structures
- Hydraulic impact assessment of modified or new structures

(source: http://www.usbr.gov/pmts/sediment/model/u2rans/)

USFWS/USGS Index Models – Habitat Evaluation Procedures (HEP). The philosophy behind the Habitat Evaluation Procedures (HEP) is that an area can have various habitats, and that these habitats can have different suitabilities for species that may occur in that area. Further, we assume that the suitabilities can be quantified (via Habitat Suitability Indices [HSIs]) and that the different habitats have measurable areal extents. The overall suitability of an area for a species we postulate can be represented as a product of the areal extents of each habitat and the suitability of those habitats for the species.

If this is true, we may further postulate that as habitat changes through time, either by natural or human-induced processes, we can quantify the overall suitability through time by integrating the areal extent-suitability product function over time. Thus, we can quantitatively compare two or more alternative management practices of an area with regards to those practices affecting species in that area. For example, we can judge the effects of logging, mining, and cattle grazing, versus no use. Furthermore, HEP allows us to quantify the effects of mitigation (not so great a negative impact) or compensation (improve another like area to make up for lost habitat in the impacted area).

This is an important tool for land use managers, as they can quantify the effects of alternative management plans over time, and provide for mitigation and compensation that can allow fair use of the land and maintain healthy habitats for affected species.

The HEP accounting program uses the area of available habitat and Habitat Suitability Index (HSI) to compute the values needed for Habitat Evaluation Procedures (HEP) as described in the Ecological Services Manual (ESM 102) and the HEP training course Habitat Evaluation Procedures. The compiled program requires two floppy disk drives or a hard disk, and 64 kilobytes of RAM.
(source: http://www.fort.usgs.gov/products/software/hep/hep.asp)

USGS Invasion Models
USGS River Habitat Models
USGS Screening Model
USGS Wind Fetch Model
USGS/Yin Model

W-2. Two time-varying mechanistic reservoir models have been developed and are maintained and distributed for outside use: CE-QUAL-R1, a one-dimensional, vertical model; and CE-QUAL-W2, a two-dimensional (vertical and longitudinal), laterally-averaged, hydrodynamic and water quality model. These two models are widely used by the Corps of Engineers, other federal and state agencies, the private sector, and agencies in other countries. A model of reservoir tailwater quality has been developed. The Tailwater Quality Model (TWQM) computes the steady-state, longitudinal (i.e., along the stream reach) distribution of water quality downstream of a reservoir. TWQM focuses on dissolved oxygen and other constituents (e.g., reduced iron and manganese, ammonium, and sulfide) that typically cause water quality concerns immediately

downstream of deep reservoir releases. The model can be applied relatively quickly in a user-friendly environment on a personal computer. TWQM can be used to evaluate the effects of altering reservoir releases, such as adding hydropower, and to estimate the amount of tailwater required for natural recovery to better water quality conditions.
(source: http://el.erdc.usace.army.mil/elmodels/resinfo.html)

WASP. The Water Quality Analysis Simulation Pro-gram—(WASP6), an enhancement of the original WASP (Di Toro et al., 1983; Connolly and Winfield, 1984; Ambrose, R.B. et al., 1988). This model helps users interpret and predict water quality responses to natural phenomena and man-made pollution for various pollution management decisions. WASP6 is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. WASP allows the user to investigate 1, 2, and 3 dimensional systems, and a variety of pollutant types. The state variables for the given modules are given in the table below. The time-varying processes of advection, dispersion, point and diffuse mass loading and boundary exchange are represented in the model. WASP also can be linked with hydrodynamic and sediment transport models that can provide flows, depths velocities, temperature, salinity and sediment fluxes.
(source: http://www.epa.gov/athens/wwqtsc/WASP.pdf)

ZELIG . ZELIG (Urban, 1990) is an individual tree simulator that simulates the establishment, annual diameter growth, and mortality of each tree on an array of model plots. Model states are recorded in a tally of all trees on a plot, with each tree labeled by species, size (diameter), height to base of live crowns, and vigor (based on recent growth history). The competitive environment of the plot is defined by the height, leaf area, and woody biomass of each individual tree determined by allometric relationships with diameter. Plot size is defined by the primary zone of influence of a single canopy-dominant tree. The plot is considered homogeneous horizontally, but vertical heterogeneity (canopy height and height to base of crown) is simulated in some detail. Adjacent cells interact through light interception at low sun angles. Establishment and annual diameter growth is first computed under optimal (nonlimiting) conditions, and then reduced based on the constraints of available light, soil moisture, soil fertility, and temperature. Climate effects are summed across simulated months. Seedling establishment, mortality, and regeneration are computed stochastically, while the growth stage is largely deterministic. Simulations can start or stop at any point within the life cycle of a forest.

The objective of the ZELIG model is to understand the dynamics of forest growth and canopy characteristics through a simulation model of the dynamics of tree species. The initial elements of this model were developed by Dan Botkin and colleagues about 20 years ago (JABOWA) developed further on by Shugart and co-workers (e.g. FORET) resulting on one developmental line in ZELIG and successors.
(source: http://eco.wiz.uni-kassel.de/model_db/mdb/zelig.html)