An Adaptive Management Approach for Summer Water Level Reductions on the Upper Mississippi River System

by

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Contents

Executive Summary

The primary purpose of this report is to provide an adaptive management approach for learning more about summer water level reductions (drawdowns) as a management tool, including where and how drawdowns can be applied most effectively within the Upper Mississippi River System. Our approach is not an attempt to achieve a specific management objective, but to generate new knowledge directly related to increasing managers' ability to predict the effects of drawdowns. The report reviews previous drawdowns conducted within the system and provides specific recommendations for learning more about the lesser known effects of drawdowns and how the outcomes can be influenced by different implementation strategies and local conditions. The knowledge gained can be used by managers to determine how best to implement drawdowns in different parts of the UMRS to help achieve management goals. The information and recommendations for learning contained in the report are derived from results of previous drawdown projects, insights from regional disciplinary experts, and the experience of the authors in experimental design, modeling, and monitoring.

Modeling is a critical part of adaptive management. Planning and implementation of drawdowns can benefit from the use of conceptual, empirical, and simulation models. In this report we present conceptual models that express current understanding regarding functioning of the UMRS as related to drawdowns and highlight interactions among key ecological components of the system. The models were developed within the constraints of drawdown timing, magnitude (depth), and spatial differences in effects (longitudinal and lateral) with emphasis on ecological processes affected by drawdowns. With input from regional experts, we focused on the responses of vegetation, fish, mussels, other invertebrates, and birds to drawdowns. Other faunal groups were considered, but not included due to lack of expertise. The conceptual models reflect current understanding about relations and interactions among system components, the expected strength of those interactions, potential responses of system components to drawdowns, likelihood of the response occurring, and key uncertainties that limit our ability to make accurate predictions of effects (Table 1, Fig. 4-10).

Based on this current understanding, the main questions still associated with drawdowns include (1) the effects of frequency of drawdowns (from once every few years to multiple years in succession); (2) timing of the beginning of drawdowns (follow the descending arm of the flood pulse versus always beginning in early summer); (3) long-term benefits (greater than 5-6 years), especially as compared to known short-term losses (e.g., mortality of mussels in exposed areas, loss of submersed vegetation in exposed areas, cost of advanced dredging); and (4) the effects in northern (above pool 14) versus southern pools (pool 14 and below, and the Illinois River). Adaptive management can effectively address these questions to reduce uncertainty in

predictions of drawdown effects and help determine if different implementation strategies are needed in different parts of the system.

Given that drawdowns will continue to be used as a management tool on the UMRS, we suggest that some drawdowns be conducted in an adaptive management context that helps meet management objectives, but also provides opportunities for addressing the questions listed above. We propose two different, but interrelated, experimental designs to address these questions. Both designs call for conducting multiple drawdowns in multiple pools (2-4 pools) to allow direct comparison of results and produce rapid learning. However, the report does not provide a detailed scope of work for carrying out the designs. If managers choose to implement one of the experimental designs, specifics of choosing appropriate pools and developing a monitoring plan will need to be determined through collaboration among managers, researchers, and statisticians. We suggest characteristics to consider in selecting treatment and reference pools (study sites) and also provide guidance for developing a monitoring plan. Some aspects of these two designs could be implemented individually, but by implementing individual elements, direct comparisons of some design features will not be possible and the potential for learning will be reduced.

The conceptual models presented in this report suggest many possible components and variables that could be monitored to evaluate responses under the experimental designs. As part of developing the specifics for implementing an experimental design, managers will need to determine the priority questions to be addressed and monitoring strategies needed for measuring project success and learning. We suggest that monitoring focus mainly on variables related to processes and cause-and-effect relations (learning variables). This information will be used primarily by managers and researchers to help identify and quantify mechanisms that underlie drawdown responses. In addition, some broader monitoring of species and communities responses (status variables) or aggregate measures of ecological condition (report card variables) is needed to communicate to stakeholders, legislators, and administrators the effectiveness of management actions or significant findings that address critical questions. We provide suggestions for different variables that could be included in each of these categories.

In addition to monitoring data, information obtained from focused studies or experiments can be used to address specific questions about mechanisms that determine responses to drawdowns. We suggest some potentially useful studies including seed bank evaluations, relation of ground water elevation to surface water elevation, and effects of planting or exclosures on vegetation responses (especially in southern pools). Some of these studies could be carried out independently and some performed within the pools used for the experimental designs.

Given the uncertainties identified in the conceptual models, we suggest that the most critical effects to evaluate relate to long term response of mussels, fish, and vegetation, including responses to frequent drawdowns, and differences in response between northern and southern pools. Under the proposed experimental designs, addressing these uncertainties would probably require 8-12 years to implement and monitor the first iteration of adaptive management. In addition, several years of pre-drawdown data should be included in the monitoring plan. This time frame will depend on which specific pools are chosen, the availability of existing data and sampling efforts (e.g., the Long Term Resource Monitoring Program), and variability in response variables. For any monitoring plan, managers will need to prioritize the information to be obtained, match the scope of monitoring to funding available, and develop economical monitoring programs that provide needed information as efficiently as possible. For example, monitoring the early life stages of mussels, fish, and forest trees should provide information on their population responses more quickly than concentrating on adults.

Compared to standard management approaches, an adaptive management plan may be more costly initially, but more rapid learning under adaptive management should result in more cost effective management in the future. Cost effectiveness for drawdowns will probably relate mainly to how often they should be conducted and whether different methods or implementation strategies are needed in northern and southern pools.

New information gained must be communicated, incorporated into the knowledge base, and used to determine next steps and improve effectiveness of the design. This is especially true in adaptive management, which requires stakeholder engagement and assessment of progress at frequent intervals. Before implementing an adaptive management plan, managers and researchers should determine when specific decision points will be reached. A decision point is a time when data analyses and assessments are conducted to determine next steps. For the experimental designs proposed in this report, we suggest time frames when various decision points may be reached. One obvious point is the end of the first iteration of the adaptive management cycle. At that point, next steps could include additional monitoring, conducting more iterations of the same design, changing the approach to learn about new questions, or returning to previous water level management practices. Agency procedures need to be flexible to allow for modifications to project plans in ways that can overcome obstacles without compromising the ability to achieve project goals. The final outcome of this process for drawdowns is expected to be development and implementation of new operational strategies that can be tailored to individual dams based on knowledge gained.

Data and information derived from adaptive management should be reported regularly to interested parties to keep them engaged and updated on progress. Different reporting formats (e.g., tables, graphs, maps, GIS presentations, animation, written or verbal summaries) may be required to communicate with different user communities (e.g., scientists, managers, regulators). Rigorous analyses will be required for scientific communications, but less detailed data summarization might be sufficient to report general trends, changes in condition, or project performance to a lay audience. A discussion of the accuracy and reliability of the information should be included in all reports.

The process we used in developing this initial adaptive management plan for drawdowns can be applied to virtually any management actions taken on the UMRS. The approach could be applied to other management techniques, or could begin with broad management objectives, then assess multiple techniques to learn more about which techniques, singly or in combination, are most effective at achieving those objectives. Our application of this process to summer drawdowns was facilitated by a considerable amount of data and information derived from pilot studies and demonstration projects. An application to management actions for which we have little or no experience on the UMRS (e.g., fish passage, side channel restoration, floodplain restoration) may require more extensive experimental designs. Alternatively, an analysis of the issues associated with these techniques may suggest conducting pilot projects, similar to the approach taken initially with drawdowns, to provide better information for developing a larger-scale adaptive management approach. Overall, the UMRS provides outstanding opportunities for learning through adaptive management that can lead to more effective management of this, and other, large river systems.

Chapter 1. Introduction and background for water level management

Purpose of this report

The purpose of this report is to suggest an approach for learning more about summer water level reductions (drawdowns) as a management tool, including where and how drawdowns can be applied most effectively within the Upper Mississippi River System (UMRS). The Science Panel of the U.S. Army Corps of Engineers Navigation and Ecosystem Sustainability Program (of which the authors are members) was tasked with developing this approach. Summer drawdowns have been conducted as pilot projects on this system since the 1990's. Evaluations of those projects have provided much information on the effects of drawdowns. This report is based primarily on an assessment of reports and published literature derived from these evaluations. We used that information to develop conceptual models regarding how drawdowns affect system function, and to determine what effects are still uncertain given current knowledge.

Recently there have been requests to incorporate drawdowns into standard operation of UMRS dams where appropriate (WLMTF 2008, Landwehr et al. 2005). Landwehr et al. (2005) discussed opportunities for water level management on the UMRS, including summer drawdowns. We build upon the Landwehr et al. (2005) report, previous evaluations of drawdowns in the UMRS, and conceptual models to suggest how UMRS managers can design and evaluate a series of drawdowns as learning tools. The primary goal is to learn about the less well known effects of drawdowns and how the outcomes of drawdowns can be affected by different implementation strategies and different local conditions. Managers can use this new knowledge to determine how to best implement drawdowns in different parts of the UMRS to help achieve management goals.

Dam construction and water level management

In 1927, the U.S. Congress authorized the U.S. Army Corps of Engineers to increase the depth of the main channel in the Upper Mississippi River System (UMRS) from 6 feet to 9 feet. The Corps of Engineers accomplished this by building a system of locks and dams, mainly during the 1930's (Fig. 1). On the Upper Mississippi River, 29 dams were built between Minneapolis, Minnesota, and St. Louis, Missouri, and eight dams were built on the Illinois River. The dams for the 9-foot Navigation Channel Project were designed primarily to increase water elevation at low flows, thus providing the 9 foot deep channel for commercial navigation when discharge was low. Most dams were designed with relatively low heads of approximately 5 to 20 feet, and have little effect on water elevations during high flows (Wlosinski and Hill 1995, Wilcox et al. 2004).

The dams have little effect on total river discharge, but they modify lateral flow distribution and the normal annual cycle of water elevation (Fig. 2). These modifications resulted in a variety of physical effects. The most obvious effect was the division of the river corridor into a series of navigation impoundments, called pools. Within each pool, increased water levels inundated floodplain areas, which increased the amount of aquatic habitat. Much of that land area has remained inundated since the 1930's.

Higher water elevation also affected a variety of conditions and processes that were not as obvious (Fremling 2005). Because water elevation was now higher during the summer and winter low flow periods, the annual range of water elevations was reduced (Theiling and Nestler, 2010). Increased water levels reduced the elevation gradient of the water surface, which reduced current velocities and increased water retention time within a pool. Resulting changes in hydraulic conditions throughout each pool affected transport of sediments and other materials, with substantial increases in total sediment deposition within pools. The elevation of the groundwater table was also increased throughout much of the floodplain. Higher surface and groundwater levels changed the hydrology of many wetlands and riparian areas, and also changed physical and chemical conditions in soils and sediments, such as redox potentials, decomposition rates, and rates of nutrient transformations.

Impoundment produced larger areas of open water and increased wind fetch, primarily in the lower portion of pools. This caused increased erosion of shorelines, including complete loss of many islands and channels, combined with subsequent filling of deep areas. The overall result was a loss of depth diversity within pools.

These physical changes resulted in many ecological changes. Initially, there was an increase in biotic production, as is typical with new impoundments. But, over time, consistently high water levels and the lack of substrate drying increased the water content of many sediments, resulting in unconsolidated, flocculent sediments that were less suitable habitats for plants, invertebrates, and mussels. Increased wind fetch and wave energy, increased resuspension of unconsolidated sediments, which increased turbidity and reduced light penetration necessary for plant growth. These combined conditions produced a general loss of aquatic vegetation, especially emergent vegetation. In addition, elevated ground water tables favored tree species that could tolerate wetter conditions (primarily silver maple), which reduced diversity of forest communities. These changes in vegetation reduced habitat suitability and food availability for many fishes, waterfowl and other birds, and mammals (Fremling 2005).

Drawdowns – a management technique to help restore natural hydrology

One method to help overcome the negative effects listed above is to manage water levels differently through modified dam operations. Water-level management is one tool that can help restore a more natural hydrograph, which helps to address many of the NESP system-level objectives (Galat et al. 2007).

In particular, managers have experimented with summer water level reductions, or drawdowns, to partially emulate the pre-dam summer hydrograph in a system that has been subject to altered hydrology continuously over the last 70 years. The overall goal of drawdowns has been to induce changes in processes that will affect ecological function, and produce positive changes in structure and composition of biota (UMRCC 2000; Galat et al. 2007, Landwehr et al. 2005), most often with a focus on emergent aquatic vegetation (USACOE 2004; Water Level Management Task Force 2007, 2008). However, in addition to benefits, potential negative effects (both ecological and social) can result from drawdowns, such as reduced navigation capacity and increased mortality of biota in the exposed areas (Woltemade 1997; Johnson 1998).

Drawdowns have been implemented in a manner that maintains commercial and most recreational navigation. This has been accomplished by setting appropriate maximum drawdown depths (minimum water elevations) and by advanced dredging to a depth deeper than normal before the drawdown. In addition, discharge must be at appropriate levels to enable a drawdown. If discharge is too low during a drawdown, channel depth becomes too low to maintain navigation and the depth of drawdown is reduced. If discharge is too high, the tailwater below the dam becomes too high and it is physically impossible to maintain the drawdown, thus water levels rise and drawdown depth is reduced.

A drawdown reduces summer water elevations, which creates four lateral zones of influence based on elevation (Fig. 3). The highest area (riparian zone) is typically dry during summer under current water level management. During drawdown, this zone experiences a lower ground water table, which dries the soil to deeper depths and reduces water levels in isolated water bodies and wetlands. The zone below the riparian zone is the area that is exposed during drawdown, perhaps for the first time in over 70 years. This area experiences drying, aeration, and compaction of sediments, and provides conditions conducive to germination of emergent plants. The third area, called the "shifted littoral zone," is still submerged, but water depths are shallower than normal so light can now penetrate to the bottom in areas that were previously too deep. If drawdown depth changes (due to changes in discharge or by management actions), the boundary between the exposed area and shifted littoral zone changes, as does the groundwater depth in the riparian zone. The fourth zone is the deep water zone, where the primary effect is changes in current velocity.

Evaluations of drawdowns on the Upper Mississippi River System

Historically, management of water levels on the UMRS has varied (Theiling and Nestler 2010), but since the 1990's, summer drawdown studies have been conducted on various small-scale, closed systems (e.g., Lizzy Pauls Pond and Small Bay West in Pool 5, Peck Lake in Pool 9), and at pool-wide scales on Pools 5, 8, 24, 25, and 26. The maximum level of drawdown in these studies has varied from about 1-4 feet. Evaluations of these studies have all been relatively short term (up to five years), and have shown the following results:

Aquatic vegetation: All drawdowns showed a consistent increase in emergent aquatic vegetation, which was directly related to duration of exposure. In upper pools, this response was most pronounced when drawdowns were implemented for two consecutive years, with greater abundance of perennial vegetation in the second year (WLMTF 2007). Some emergent vegetation has persisted for more than 5 years in Pool 8. In southern pools (24, 25, and 26), the response was mainly in annual plants and was more variable among years depending on discharge (Wlosinski et al. 2000, Garvey et al. 2004). A seed bank study conducted in Pool 8 (Kenow and Lyons 2009) found that a diverse species mix of annual and perennial emergents and submersed plants. A similar study conducted in Pool 18 found a lower diversity of plants and very few submersed plants in the seed bank (unpublished data, Amber Andress, U.S. Fish and Wildlife Service, Rock Island, Illinois). Submersed vegetation increased in Pool 5 (Kenow et al. 2007), but in Pool 8 no changes could be directly attributed to drawdowns (WLMTF 2007). Increased vegetation produced higher levels of benthic organic matter (Garvey et al. 2004). Many of the responses of aquatic vegetation to drawdowns were similar to responses documented from water level management in other systems (see Fredrickson and Taylor 1982, Woltemade 1997, and references therein).

Fish: No negative effects were documented on fish abundance (WLMTF 2007, Garvey et al. 2004) or diversity (Garvey et al. 2004, Wlosinski et al. 2000). Variance in fish data among these studies was relatively high, which limited ability to detect change. Some increase in forage fishes was observed (WLMTF 2007, Garvey et al. 2004) and use of newly vegetated areas, primarily by young-of-year fishes, was noted (Garvey et al. 2004).

Native mussels and zebra mussels: Mortality of native mussels in dewatered areas was observed in Pools 5 and 8 (WLMTF 2007), although mortality rates were not estimated. In Pool 26, aerial exposure of up to 24 hours produced high mortality of zebra mussels, but no increase in mortality of native mussels (Tucker et al. 1997). Research is ongoing to investigate the depth distribution of native mussels within pools and the behavior and mortality rates of mussels in shallow areas affected by drawdowns. Initial results from Pools 5, 6, and 18 indicate that a relatively small proportion (1 to 2%, J. Rogala, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, personal communication) of the total mussel population in a pool resides in areas that are <0.5 m deep during summer.

Water quality: Exposed sediments with high organic matter content became more consolidated (WLMTF 2007). Drawdowns affected nitrogen transformations in the sediment, but different processes interacted to result in no net reduction of nitrogen in sediments (Cavanaugh et al. 2006). Increased metabolic activity of new beds of plants in backwaters contributed to increased dissolved oxygen levels during the day, but also greater diurnal fluctuations (Sullivan 2003; J. Sullivan, Wisconsin Department of Natural Resources, La Crosse, Wisconsin, unpublished data). In Pool 8, sediment resuspension was more affected by discharge than by wind speed, whereas in Pool 5, wind speed was more important (Sullivan 2003, J. Sullivan, unpublished data). In Pool 5, increased water clarity in newly created submersed plant beds resulted in increased light penetration and may have resulted in increased surface water temperatures (J. Sullivan, unpublished data). No changes in overall mean levels of dissolved oxygen, nutrients, turbidity, total suspended solids, or chlorophyll a were observed during the drawdown or one year after (WLMTF 2007, Burdis 2009).

Invertebrates: In Pool 25, the abundances of macroinvertebrates and zooplankton were higher in areas with vegetation resulting from the drawdown (Garvey et al. 2004). Invertebrates appeared to recolonize exposed areas soon after reflooding in southern pools, but this was not quantified (Wlosinski et al. 2000).

Birds: Shorebird use increased in exposed areas and waterfowl made greater use of areas where aquatic vegetation had increased (WLMTF 2007). In Pool 25, water fowl abundance was variable, but drawdowns generally improved habitat for migrating waterfowl (Garvey et al. 2004).

Navigation and dredging: The effects on commercial and recreational navigation were minimal (Wlosinski et al. 2000, WLMTF 2007). This was due mainly to advanced dredging to maintain sufficient depth in the main channel and recreational access channels and agreements to reduce the depth of drawdown if discharge levels produced conditions that were too shallow. In addition, the maximum depth of drawdown was maintained only when flow was sufficient, and water levels were increased when flows were too low. Although recreational access to the main channel was maintained, access to some shallow backwater areas was reduced during drawdowns. However, in southern pools, sandbars exposed during drawdowns became recreational areas (Wlosinski et al. 2000). In Pools 8 and 5, advanced dredging in the main channel during the year of the drawdown reduced dredging needs for two years afterwards (WLMTF 2007). However, by the third year, dredging volumes increased over historical rates by 11% in Pool 8 and 80% in Pool 5 (J. Hendrickson, U.S. Army Corps of Engineers, St. Paul, Minnesota, unpublished data).

Hydrodynamics: The percentage of flow conveyed by the main channel increased due to reduced flow in side channels (WLMTF 2007, J. Hendrickson, personal communication). This caused mean current velocity in the main channel to increase from 1.83 fps without drawdown to 2.35 fps during the drawdown (Pool 8), and increased instantaneous sediment transport capacity in the main channel (Pool 8 & 5).

Spatial distribution of effects within pools: In all pool-wide drawdowns, the water level reduction and its effects were most pronounced in the lower portion of the pool.

Variability in water levels: In all pools, it was not possible to maintain the maximum drawdown continuously due to variation in flows, and in some locations within pools there was no water level reduction during large portions of the summer. When drawdowns used a mid-pool control point, variation in water levels was greater in the lower portion of the pool compared to mid-pool (Garvey et al. 2004).

Overall, evaluations of drawdowns on the UMRS so far have shown some consistent benefits, mainly increased abundance of aquatic vegetation, but that response was not as robust in southern pools. A few negative ecological effects were evident, the most substantial being direct mortality of native mussels in exposed areas. Drawdowns did modify ecological processes, including changes in hydrodynamics, sediment chemistry, plant germination, and plant growth. Increased annual water level variation helped to promote diversity of habitats and biota (Flinn et al. 2005, 2008). However, most evaluations of ecological effects were designed to document expected outcomes and were relatively short-term (up to a few years). In northern pools, evaluations were based on a single drawdown episode (which typically included two successive years of drawdown). Thus, although evaluations of drawdowns have increased our knowledge of their effects, there are many outcomes and interactions that remain uncertain, especially longer term effects (more than 4-5 years) and effects resulting from multiple, consecutive drawdowns. To help define potential effects and interactions that may be critical to management, we developed conceptual models of the effects of drawdowns on specific ecosystem components.

Chapter 2: Conceptual models of drawdown effects

Modeling is a critical part of adaptive management and can involve conceptual models, simulation models, empirical models or all of these. Models provide a vehicle for expressing current understanding about how we think a system functions and they provide a concise way to communicate that information among stakeholders. Conceptual models:

a. present information on causal relations and feedbacks among system drivers and variables that express a collective perspective on how the system functions,

b. identify broad expectations (direction, not detailed numerical forecasts),

c. present hypotheses about the positive and negative responses that restoration actions are likely to elicit in both target and non-target variables,

d. present collective opinions about the relative strength and importance of relations and identify knowledge gaps and uncertainties that reduce our confidence in predictions from the model,

e. set the stage for testing of hypotheses presented in the model and help identify the pre- and post-monitoring needed to evaluate those hypotheses.

A system-based conceptual model of the UMRS was developed by Lubinski and Barko (2003. Fig 4). For this report, we drew from that system model, from the evaluations of drawdowns on the UMRS, and from basic understanding of river and wetland ecology to develop more detailed conceptual models regarding how the river ecosystem will likely respond to drawdowns (Figs. 5-10). These models represent we consider to be possible effects of drawdowns with an associated level of confidence (likelihood) that the effect will occur, and with a set of questions that describe aspects of effects or associated processes that are still unknown (Table 1).

We began by developing a general model of the direct physical effects of drawdowns, then developed models of how specific ecosystem components should react to those physical changes. We developed specific conceptual models for vegetation, fishes, mussels, other invertebrates, and birds. Other components of the ecosystem are likely to be affected, but we felt these components were most critical to river managers. We solicited input from experts familiar with the river (see Acknowledgments section) to develop relations that identify how each component would likely respond to drawdowns, the processes linking the drawdown to the response, and uncertainties associated with those relations. Some suggested relations were considered too uncertain or unlikely and were dropped. However, some effects that may be unlikely, but could be important if they occur, were included. These models can be updated as future observations lead to a better understanding of these relationships and effects.

Models were developed within the constraints listed below. These constraints were necessary to distinguish relationships that were outside the specific area of management interest, and to promote consistent input from contributing experts.

Timing. We assume drawdowns will be conducted during the growing season. Drawdowns can be conducted for one or more years, consecutively or on an irregular schedule. The effects of drawdowns might be expressed during the year of the drawdown, in later years after a lag period, or only after multiple drawdowns. Multiple drawdowns are those conducted for more than 2 years in a row. Multiple drawdowns could occur in successive years or with a return to standard water level management between drawdowns. An effect may be evident for only one year or may last for many years. Long-term responses are those that occur more than 4-5 years after an initial drawdown.

Spatial scope. We considered effects in the pool where the drawdown occurred (effects in nearby pools were outside our scope) and expect that more effects will occur in the lower reaches of pools were depth of drawdown will be greatest.

Magnitude of drawdown. We assume that navigation (commercial and recreational) will be maintained during a drawdown, thus keeping drawdown depths to about 1.5 ft – 2.5 ft in the upper pools of the UMRS, and up to about 4 ft in the lower pools.

Processes. In addition to the biological components, we tried to determine how drawdowns restore “natural processes” that were modified by impoundment and subsequent water level management strategies.

Discharge range constraints. For each pool, there is a range of river discharges within which maximum drawdown can be achieved. Drawdowns can be reduced, delayed, or terminated when river discharges are outside the acceptable range. Thus, variation in discharge can cause variation in magnitude and effect of drawdowns, both within and among years.

Conceptual model relations and uncertainties for specific components

The primary effects and uncertainties identified in the conceptual models are described below and are presented visually in Figures 5-10 and in tabular form in Table 1, along with a judgment of the likelihood that the effect will occur. In many of these models, we refer to changes in “abundance,” which could be expressed by a variety of measures, such as numbers, density, biomass, distribution, use days, etc.

Physical and chemical effects of drawdowns

Drawdowns are designed to more closely approximate the natural, pre-dam summer decline in water levels in terms of magnitude, timing, and duration. Drawdowns will cause three main physical changes (Fig. 5): decreased water levels, decreased water volume in the pool, and shifting the littoral area offshore.

The combination of decreased water levels and less water volume will increase the slope of the water surface within a pool, concentrate flow in primary and secondary channels, and increase current velocity in major channels and tributary mouths. These effects will be greatest in the lower end of the pool where drawdown is greatest. This should increase sediment transport to, and deposition in, the main channel, but may also increase export from the pool. Effects on sediment dynamics in off channel areas will likely depend on pool-specific geomorphology, including local effects of tributaries.

Reduced connection of the main channel with off channel areas should increase retention time in backwaters, which should increase temperatures and diel variation in dissolved oxygen in backwaters. This will affect nutrient cycling, as will changes in sediment chemistry, nutrient storage in plants, and rates of organic matter decomposition, especially for senescent aquatic plants. Nitrogen processing in the UMRS has been studied extensively (James et al. 2004, Richardson et al. 2004, Strauss et al. 2004, Cavanaugh et al. 2006, Strauss et al. 2006, Houser and Richardson 2010), but storage of nutrients and carbon in both woody and aquatic plants, and the fate of stored nutrients when those plants die, are poorly known. In addition, if aquatic plant biomass increases, there may be increased oxygen demand from decomposition over winter, which could suppress oxygen levels. Thus, although changes in each of these individual processes are likely, many of these effects and their interactions are non-linear and very difficult to predict, making some local effects (e.g., oxygen dynamics, and some pool-wide effects (e.g., nutrient export rates) very uncertain.

All of these effects will be influenced by annual and short term (daily to weekly) variation in discharge and water levels. When a drawdown is implemented, water levels will be lower than typical under current dam operations, but will still be substantially higher than they would have been at the same discharge before dams. Because a drawdown can only be maintained under a specific range of discharges (which varies by pool, see Landwehr et al. (2005)), typical changes in discharge during the summer will not allow managers to maintain a continuous drawdown to the full level desired, thus variation in water levels is expected to increase during a drawdown. The degree of variation will be different among pools, among years, and among locations within a pool (e.g., mid-pool versus lower pool). However, variation in water levels within and among years is more consistent with historical conditions than is holding water levels consistently high under current water management strategies. Some degree of variation in water levels can help increase habitat diversity (Garvey et al. 2004), but the optimum level of variation is unknown. Many of these changes will result in conditions that more closely resemble historic conditions in this system, including shoreline exposure during low discharge, more flow concentrated in primary channels, and variability in dissolved oxygen in backwaters. These physical and chemical changes should have direct effects on the five biotic variables modeled, and on interactions among them.

<u>Effects on Vegetation</u>

The most consistent effect observed for drawdowns was increased abundance of emergent vegetation on exposed shorelines in year(s) of the drawdown (Fig. 6). The processes that produce annual emergent plants rather than perennials in lower pools are poorly known, but may be related to a poor seed bank for perennials or the relatively short drawdown period in lower pools. Increased abundance of perennial emergents may persist for a few years after returning to standard water level management, but over time their abundance will likely decrease at an unknown rate. For annual emergents, a return to standard water level management will likely result in a rapid decline in abundance.

Submersed vegetation will be eliminated in exposed areas in the year of the drawdown, but may increase within the shifted littoral zone where water was previously too deep. This response will depend on local bathymetry and transparency, which will define the extent of the new littoral area, and also on substrate suitability, seed bank, water level variation, and possibly herbivory. If submersed vegetation grows in the new littoral area, a critical question is whether that will increase the likelihood that it will grow in those areas in succeeding years without a drawdown.

Increased abundance of aquatic plants should reduce wave energy, resulting in reduced shoreline erosion and sediment resuspension, and increased water clarity (at least locally). Better water clarity should result in more plant growth and may create a positive feedback loop that could lead to an alternate stable state dominated by aquatic plants (Scheffer and Jeppesen 1998). The strength of these effects and their interactions, along with the role of high nutrient levels, are poorly known, thus the prospect of moving to a new stable state is uncertain.

The lower elevation of groundwater will dry soils in terrestrial areas. This may cause some wetlands to dry out and some areas that were shallow, open water to become wetlands. This could change the spatial distribution and total area of wetlands within the pool, but effects will depend on local geomorphology and thus, will be pool specific. Dryer soils should result in better germination and survival of plant species that prefer dryer conditions. But, to persist, these plants must survive a return to higher (normal) water levels during fall and winter after a drawdown, and in summer in years without a drawdown. Thus, the long term effect of drawdowns on floodplain vegetation communities is uncertain, but we would not expect a substantial response unless drawdowns are repeated very frequently. However, once established, forest communities may transpire enough water that they can maintain dryer conditions in their root zones, providing a positive feedback loop that may result in an alternate stable state.

Additional uncertainties regarding plants include the success of native species versus exotics during drawdowns, effects on phytoplankton production and species composition, and effects on benthic algal growth.

Effects on Fish

We expect that fish abundance will increase due mainly to increased abundance of aquatic plants that provide better cover and food resources (invertebrate prey) leading to better growth and survival of young and small-bodied fishes (Fig. 7). However, increased biomass of dead plants in winter may increase decomposition rates and reduce dissolved oxygen levels, potentially increasing over-winter fish mortality rates in those areas. These effects may occur in the year of the drawdown and in any future years when vegetation abundance remains high (Janecek 1988, Johnson and Jennings 1998), but there will likely be a time lag in increased abundance of the adult population. Ultimately, this should increase angling opportunities.

This may be countered by other effects. Exposing shorelines may disrupt spawning or hatching success of littoral nesting species, potentially making year class strength lower or more variable. This may be offset by a density-dependent compensatory increase in survival and growth of juvenile fishes from weak year classes. Also, increased abundance of prey fishes and reduced volume of the pool may increase food availability for piscivorous fishes, but high plant density may reduce predator’s capture efficiency. These competing responses are poorly understood.

Reduced water levels in backwaters may increase water temperatures and hypoxia, increase fish density, and strand fish if some areas become isolated during the drawdown. These effects may increase predation rates and mortality in backwaters or cause fish to move to other locations. The extent of this effect will depend on pool geomorphology and, thus, is likely to be pool-specific. Few fish mortality events have been observed during drawdowns, but no specific evaluations were conducted.

The interactions of the effects above on long-term fish population dynamics have not been studied, nor have effects on the response of native fishes compared to exotic species.

Effects on Mussels

Native mussels and zebra mussels in exposed areas will experience increased mortality during the drawdown, although some mussels will likely survive by moving to deeper water or by burrowing into the substrate (Fig. 8). Because a relatively small proportion of the mussel population resides in shallow areas ($<$ 0.5 m), pool-wide effects should be minor. In addition, mortality in exposed areas may decrease with multiple drawdowns because there should be fewer mussels in shallow areas. However, this effect depends on the interaction between the frequency of drawdowns and the rate at which mussels recolonize exposed areas, which is currently unknown. Reduced numbers of zebra mussels may increase survival of native mussels that remain in shallow water.

During drawdowns, the increased velocity in the main channel at low discharges will create hydraulic conditions (e.g., current velocity and shear stress) that are more favorable to survival of native mussels. Increased velocity and reduced pool volume should increase delivery of food resources in the main channel and should concentrate fish hosts for mussels. These effects should increase mussel growth and reproduction of summer spawning mussels in the year of the drawdown.

Drawdowns should make conditions in channels more like historic conditions and more favorable for mussels, especially lotic-adapted species whose numbers have declined historically. Over multiple drawdowns, this increase in habitat suitability should compensate for short term mortality in shallow areas. However, many of these effects are undocumented and should be evaluated in the field.

Effects on Benthic invertebrates

Benthic invertebrates should experience increased mortality in exposed areas during the drawdown (Fig. 9). They will probably repopulate these areas quickly after the drawdown ends, but neither mortality nor repopulation rates have been studied during UMRS drawdowns. Increases in aquatic plants should provide a large increase in habitat and food resources for invertebrates resulting in increased abundance, species richness, and production both during and after the drawdown. Increased food delivery and hydraulic diversity in channel habitats should increase species richness and production of invertebrates there.

Effects on Birds

The abundance of migrating shorebirds should increase during the drawdown due to creation of new feeding areas on exposed substrates (Fig. 10). Increases in abundance of plants that are food for waterfowl (seeds, tubers) should increase waterfowl use days, especially during migrations in the year of the drawdown and possibly in future years if those plants persist. This increase in food energy available during migration should increase energetic fitness and reproductive potential of waterfowl using the river corridor. Increased concentration of fishes in a smaller volume of water should increase food availability for wading birds and the abundance of wading birds during the drawdown. If abundance of small fishes increases in years following a drawdown, then this effect may persist. Any increases in bird abundance should increase opportunities for bird watching and hunting.

Unknowns for birds include the effects on song birds and neotropical migrant birds, which will likely depend on the response of terrestrial vegetation, and effects of changes in aquatic plant composition on brood rearing success.

The conceptual models above include the components we considered most important after discussions with managers and technical experts. However, models for other components are possible and may be valuable. For example, we did not include a model for amphibians and reptiles, mainly due to a lack of strong expertise and information (they were not evaluated during previous drawdowns). However, because significant effects of drawdowns are likely to occur along land/water interfaces (e.g., shorelines, wetlands, isolated water bodies) where many reptiles and amphibians reside, they are likely to experience both direct and indirect effects. If a conceptual model for these organisms is desired, it can probably be developed most effectively through a workshop involving experts in the field, including experts in floodplain and wetland ecology. The model could help in developing monitoring plans or focused investigations to examine hypothesized relations and responses. Similar approaches could be applied to other biotic communities that managers may wish to explore.

The conceptual models developed for drawdowns were built on information derived from previous drawdown experiments and directly related research. They incorporate both current knowledge and uncertainties regarding the effects of drawdowns (Table 1). However, the available information was incomplete and did not address some critical relations and environmental conditions that could affect important responses. Evidence so far indicates that positive effects from drawdowns outweigh observed negative effects. However, there may be negative effects that we have not yet observed. In addition, the question of whether hypothesized long-term benefits will outweigh short term costs (e.g., regarding native mussel mortality in exposed areas during drawdowns and potential pool-wide population increases following drawdowns) is untested.

The relations and questions embodied in these conceptual models can be expressed as learning objectives that provide an excellent opportunity for learning through adaptive management. Many of these learning objectives are not unique to water level management, but represent basic knowledge gaps that apply to other management questions or techniques. Evaluations of drawdowns provide an opportunity to address these questions, then broadly apply the knowledge gained. In addition, the conceptual models and information from evaluations can be used to develop quantitative simulation models that can be used as tools for exploring the potential effects of drawdowns under different ecological conditions and implementation strategies.

As drawdowns continue to be used as a management tool on the UMRS, we suggest that some drawdowns be conducted in ways that are expected to help meet management objectives, but also provide the most effective learning opportunities. The next step is to devise a plan to address questions and uncertainties and provide a better understanding of how river processes are modified by environmental conditions and different drawdown strategies. Conducting drawdowns for optimal learning may be more costly than a typical drawdown, but the knowledge gained should help managers optimize drawdowns techniques and minimize costs in the future.

Chapter 3: Developing an Adaptive Management Approach to Continued Learning about the Effects of Drawdowns

The most efficient approach to continued learning about drawdowns is likely to be a combination of focused research and long-term evaluations (Fig. 11) of specifically designed drawdown experiments in an adaptive management framework. The design must consider what managers already know and what they still don't know, as expressed in the conceptual models, to develop learning objectives that drive the design and evaluations. Our approach is not an attempt to achieve a specific management objective, but to generate new knowledge directly related to increasing managers' ability to predict the effects of drawdowns. This should provide information that will clarify benefits and costs among drawdown options, help reduce negative consequences, and help define the role of drawdowns among the multiple tools available to managers. The ultimate goal is improved management based on better understanding.

Proposed drawdowns may be outside of the recent seasonal variation in pool water levels, but they are not outside the historical range of summer river stages on the UMRS (Theiling and Nestler, 2010). More importantly, they are not outside the range to which most biota in the UMRS are evolutionarily adapted. Results from the experimental design will help define the breadth and extent of potential responses to drawdowns, which can then be used to help set quantitative management objectives. We expect that the range of responses will vary among river reaches, thus quantitative objectives will likely vary by reach. The results of this work will allow managers to define guidelines for implementing drawdowns under different conditions and potentially to target specific benefits of drawdowns to particular locations.

A typical, well-controlled experimental design involves treatments (specific contrasting actions), replicates (treatments repeated under similar conditions), randomization (assigning treatments randomly to experimental units to provide unbiased statistical analyses), and controls (experimental units that receive no treatment). Such designs provide reliable knowledge about the level of effects that should result from the treatments in light of background variability (Platt 1964, Downes et al. 2002).

However, a well-controlled experimental design is seldom feasible in natural systems, especially at large spatial scales like a UMRS pool or under the conditions present in regulated rivers. An alternative experimental design applicable to large natural systems is the *quasi-experiment* where randomization and replication are lacking, but treatments and controls are applied (Block et al. 2001). Inference is weaker in a quasi-experiment, but a quasi-experiment provides a better sample design than strictly observational or surveillance monitoring. In the UMRS, dams have provided convenient, multiple experimental units (pools) on the landscape that are similar, but not identical, and that span the longitudinal gradient of environmental conditions and drivers that exist in the system.

In reality, no true controls exist in a field experiment because no two sites, pools, or reaches are identical experimental units. However, the intent of the control in active adaptive management is to acknowledge and help account for environmental uncertainty. Similarly, true replication is not possible in rivers since downstream pools are not independent from upstream pools.

Rehabilitation projects under NESP constitute ecosystem and landscape scale management. Using these projects to develop sound management decisions that result in measurable ecological responses is more important than debates over statistical distributions and probability statements. Applying established principles of experimental and sampling design should provide the foundation for learning from NESP projects selected for an adaptive management application (Stewart-Oaten and Bence 2001, Downes et al. 2002). Newer statistical approaches, such as structured decision analysis (Holl et al. 2003, Williams et al. 2002, Nichols and Williams 2006), may prove more useful than traditional hypothesis testing. However, for these types of unreplicated ecosystem experiments, evaluation may rely more on ecological rather than statistical arguments (Carpenter et al. 1998). Results from a single iteration of an adaptive management design application may not be definitive. But, results should increase managers knowledge base and should be used determine if additional iterations are needed, and under what conditions, to continue learning effectively.

Suggested experimental designs for continued learning about drawdowns

In this section, we discuss different treatments and options for experimental designs applied to drawdowns. The goal is to address priority questions related to uncertainty about the effects of drawdowns, both positive and negative, (Table 1) under a wide range of environmental conditions within the UMRS. Any design, and its associated monitoring plan, must provide effective learning opportunities, but also be both economically and socially feasible. Here we present an outline for possible designs. If managers choose to move forward with implementing a design on the river, the details of implementation, including specific pools used for treatments and controls, and monitoring plans will still need to be determined.

Treatments within the experimental design

The conceptual models suggest three primary questions related to how to implement drawdowns that should be incorporated as treatments in an experimental design. These questions were also expressed in the Water Level Management Task Force (2008) document regarding implementing drawdowns as part of standard operations in the Corps of Engineers, St. Paul District (Pools 1-10). These three treatments are:

Treatment A) The frequency at which drawdowns are repeated.

This treatment addresses the effects of repeated drawdowns and allows assessment of how ecological processes operate through time under different frequencies for repeated drawdowns. It also allows investigation of processes that are not evident from a single drawdown and that might be invoked only after repeated drawdowns. We expect different rates of ecological processes will produce different response trajectories for effects, including immediate responses, lags, synergistic responses, and effects that will only be realized after multiple drawdowns (Fig 12). We assume that most responses will return to pre-drawdown levels after a return to standard water level management, but rates of return among components are poorly known. Thus, the question of how often to drawdown is one of achieving specific effects and maintaining them over time, given the costs involved. Repeating drawdowns over time will require different levels of effort and cost among pools (see Landwehr et al. 2005). Possible treatment levels for learning associated with frequency include:

Level 1 - <u>Drawdown only when selected benefits from the previous drawdown have degraded to a certain level, e.g., 50% of realized increases</u>.

In this approach, managers would monitor specific benefits deemed most important (e.g., emergent plant abundance) and conduct drawdowns as needed to reestablish those benefits. This approach has been suggested by managers to determine frequency and would likely involve the longest time between drawdowns. A second drawdown episode in pool 8 is being considered now and would probably be implemented no sooner than 9-10 years after the last drawdown (conducted in 2001-2002). This long interval between drawdowns probably means that any effects induced only through multiple drawdowns will be minimal under this design. Thus, this option provides little opportunity to learn about effects of multiple drawdowns, but good ability to follow the decay of responses to single drawdowns after returning to standard management. This level is probably least expensive, but if the time between drawdowns is only 4-6 years, then this level becomes the same as level 2 (below).

Level 2 - <u>Drawdown every few years, e.g., 4-6 years, on a repeating cycle</u>.

This approach would reapply drawdowns, and the ecological processes they induce, at semi-regular intervals to reinforce effects. This level is likely to require more dredging over time than option 1, but these needs will vary among pools. Compared to level 1, this level provides more opportunities for learning about effects derived from multiple drawdowns.

Level 3 - <u>Drawdown every year for a few years in a row (4-6 years), then return to normal water level management for a few years and repeat the cycle</u>.

This approach would be more likely to invoke responses that require multiple, successive drawdowns, and would reinforce those effects at semi-regular intervals. This level allows better evaluation of the trajectory of responses to successive drawdowns, including the potential asymptote of a response.

Level 4 - Drawdown every year.

This approach amounts to redefining the operational strategy for a dam to permanently lower the summer target elevation for a pool. Of the four levels, this level should provide the most natural hydrologic conditions within and among years and is most likely to emulate natural processes. This constitutes the "maximum effect" option and is most likely to invoke long-term effects and those resulting from multiple drawdowns (e.g., changes in forest communities and terrestrial vegetation). However, because the full drawdown cannot be maintained when discharge is too high or too low, natural variation in discharge will result in some years, and periods within years, that experience little or no drawdown. This inability to maintain a consistent drawdown is not considered a disadvantage of this treatment level, but is an opportunity to assess the effects of more natural variation in water levels over time. This is essentially the option used for drawdowns in Pool 25 by maintaining water levels on the low side of the normal operating band. No evaluations of long-term effects have been conducted in Pool 25. For some pools, drawing down every year could result in substantial economic and social costs, especially in the upper pools and Illinois River, thus pools for this treatment level must be selected carefully. However, it offers great learning potential.

Treatment B) Differences between northern and southern pools.

There are well documented longitudinal differences in environmental conditions within the UMRS (Koel 2001, Chick et al. 2006, Johnson & Hagerty 2008, Houser et al. 2010). This is generally evident as a dichotomy between the northern (Pool 13 and above) and southern (Pool 14 and below, plus the Illinois River) reaches of the UMRS. Environmental differences between reaches include morphometry, turbidity, habitat diversity, short-term water level variation, nutrient levels, vegetation abundance, and fish communities.

The differences in environmental conditions among these reaches may have substantial effects on the outcomes of drawdowns. Some of those differences were evident in the previous drawdown evaluations. This treatment addresses how the longitudinal changes in drivers and environmental conditions in the UMRS invoke different responses to drawdowns.

Incorporating this treatment into a design will help determine whether drawdowns should be implemented differently in northern and southern pools and whether some outcomes are less likely to occur in some reaches. Many of the positive biological responses hypothesized in the conceptual models result from increased abundance of aquatic vegetation. In Pool 25, aquatic vegetation increased, but the response was not as robust or long lasting as in northern pools. If increased vegetation does not occur under some conditions, or if increases do not persist, then related benefits may not be realized or may be short lived.

Pool-wide drawdowns are possible on pools of the Illinois River and should be considered, but various physical considerations make drawdowns less practical there (Landwehr et al. 2005). Most water level management on Illinois River pools has been accomplished at smaller scales in leveed backwater areas, where water levels can be artificially manipulated apart from dam operations. In previous assessments, no pools on the Illinois River were suggested as high priority candidates for drawdowns (Landwehr et al. 2005). However, information gained from drawdown evaluations in other locations will have applications to Illinois River pools, as well.

Treatment C) Timing for beginning drawdowns.

This treatment addresses the question of timing of shoreline exposure on the success of fish spawning in littoral areas, plant germination, shorebird abundance, settling of zebra mussel veligers, etc. There are two primary levels of treatment: choosing a start date when most spring fish spawning is over (typically in early summer and based on calendar date or water temperature), or following the descending arm of the flood pulse down to the maximum drawdown level. Following the descending arm of the flood pulse would be the most natural process for timing of drawdowns. However, timing will need to be flexible because in any year there may be social reasons (e.g., holidays with high recreation demand) or logistic reasons (e.g., delays in completing advanced dredging) that may require delaying a drawdown.

Two suggested designs for learning

We consider the three treatments identified above (A – frequency of drawdown, B – northern versus southern pools, and C – timing of start of drawdown) as those most useful for learning. However, a design incorporating three primary treatments would be too complex and costly. We suggest that an experimental design use treatments A (frequency) and B (northern versus southern pools) as primary treatments and that treatment C (timing of start) be incorporated as a nested factor within the two primary treatments. This should allow a more cost efficient design that still provides effective learning.

We suggest two options for experimental designs that differ in the treatment for frequency of repeating drawdowns. Both options would incorporate the treatment for northern versus southern pools and a nested factor for time of starting the drawdown.

Design Option 1) Use frequency Level 2 (drawdown every 4-6 years on a repeating cycle) and Level 4 (drawdown every year).

This design allows comparison of effects of a single drawdown followed by non-drawdown years with effects of drawdown every year. Drawing down every year (Level 4) will allow managers to determine if there are long-term effects that only become evident after multiple successive drawdowns. Due to annual differences in discharge, it is highly unlikely that the maximum level of drawdown will be achieved every year, and some years may see little or no drawdown. Thus, this option also allows investigation of the degree of water level variation that results from trying to maintain lower water levels every year.

We suggest assigning one pool to each treatment in a northern and southern location (= 4 pools) plus a northern and southern reference pool (2 pools) for a total of six pools in this design. Replication of either or both treatments would be ideal, but is probably not feasible due to costs and the ability to maintain independence of treatment pools within northern and southern reaches. Treatment 3 (timing for beginning drawdowns) can be incorporated into the Level 4 frequency treatment as a nested element.

For Level 2, the initial evaluation should extend through two cycles of drawdown/no drawdown (probably about 12 years). The first cycle mimics pilot drawdowns conducted in pools 5 and 8 and can be compared directly with those evaluations. After the second cycle, managers should assess what has been learned and determine if addition iterations are needed. If so, they will also need to assess whether the experimental design or the monitoring plan should be changed to create better learning opportunities.

For Level 4, information from evaluations should be assessed annually to determine if the response curves for critical variables have leveled off (reached an asymptote) and to examine the effects of variation in water levels among years induced by natural variation in discharge. Some of these results can be compared to results from Pool 25 where drawdowns were conducted in successive years. Constructing response curves for variables over time will allow managers to consider the optimal number of years for consecutive drawdowns based on marginal costs and benefits. After an asymptote is reached for critical response variables, the design should return to standard water level management with continued monitoring to determine if the responses are maintained (i.e., are self-supporting) or begin to return to previous levels. The amount of time required to achieve learning objectives for this treatment is unsure, but we expect it will occur within the 12-year time frame required for two cycles of the Level 2 treatment. At that point, managers should reassess their knowledge and determine if the treatment should be continued and if the design should be changed.

Design Option 2) Use frequency Level 3 only (drawdown for 4-6 years, then no drawdowns for 4-6 years).

This design is a compromise between the treatment levels and learning potential contained in Design Option 1. It allows evaluation of effects that may occur from successive drawdowns for 4-6 years, which can be compared to what we already know. But, it does not allow direct comparison of effects from a repeated cycle of drawdown/no drawdown to the effects from successive drawdowns over many years. Like Option 1, this option would allow investigation of the degree of water level variation among years when trying to maintain successive drawdowns.

We suggests assigning at least one pool to this treatment in a northern and southern location (minimum of 2 pools) plus a northern and southern reference pool (2 pools) for a minimum of four pools in this design. Replication of the treatment in both locations would increase statistical robustness of the results, but must be compared to costs required. Treatment 3 (timing for beginning drawdowns) can be incorporated into this design as a nested element.

For a Level 3 treatment, the initial evaluation should extend through one cycle of successive drawdown followed by no drawdown (probably about 8-10 years). Managers should then assess what has been learned and determine if addition iterations are needed. However, there is also flexibility to modify the design during the cycle, for example, to extend the number of drawdown years if managers determine that different or modified learning objectives are needed.

As indicated in these descriptions, both of these design options have flexibility in how they are pursued, given learning that occurs over time. One tenant of adaptive management is to avoid irreversible actions. Drawdowns, and most of their effects, are reversible. If unacceptable responses are identified, if costs appear too high, or if a treatment has already provided enough data to answer the critical questions, the design can be modified, including a return to standard dam operation, if desired. The adaptive management loop (Fig. 11) requires incorporation of new information to assess the need and purpose for additional iterations.

These design options are proposed primarily as learning tools. The treatments regarding frequency of drawdowns should not be regarded as endorsements for the best ways to conduct a drawdown. We propose them as effective ways to learn more and reduce uncertainty regarding the effects of drawdowns. Results from evaluations of these treatments should be used to help determine the most appropriate ways to conduct drawdowns to meet specific management objectives in specific locations.

Characteristics to consider in choosing treatment pools

For either experimental design option above, the specific pools for treatments and control must be selected by managers. This selection cannot be random because it is not possible to conduct the suggested treatments in all pools. So, analyses must be done to determine candidate pools from which final selections would be made. Initial assessments should be made based on information in Landwehr et al. (2005). Considerations for candidate treatment pools should include:

- Treatment pools should have a capability to drawdown at least 1.5 feet, preferably greater, with reasonable expectation for success in maintaining the drawdown over the summer given historic discharges. (See Landwehr et al. [2005] for an assessment of capability to drawdown in each pool.) Typically managers have chosen drawdown depths as deep as possible given tradeoffs between expected extent of ecological effects and economic and social considerations. A drawdown of greater than 1.5 feet is preferred as a learning tool because a deeper drawdown provides the best opportunity for learning quickly. At less than 1.5 feet, the magnitude of resulting effects may be difficult to separate from natural variability.

- Drawdown results may be different between pools with mid-pool control (mostly above Pool 11) versus dam-point control (mostly below Pool 10 and in the Illinois River, see Table 1 in Landwehr et al. 2005). Ideally, treatment pools should have the same control mode, but that may not be possible. Strategies for monitoring and evaluation should consider any differences in control mode and strive to produce comparable information. The information gained from these evaluations can then be used to develop computer simulation models of drawdowns. Those models can be applied to investigate differences between mid-pool and dam-point control in a single pool.

- The design requires at least one northern and one southern pool where drawdowns can be conducted for a number of consecutive years. This would require a pool with relatively low dredging requirements and where economic and social effects are acceptable, or potentially positive. Finding a candidate pool may be relatively easy in the lower reaches of the Mississippi River, where operating bands are large (about 4 ft) and dredging requirements are low. Candidates will be more difficult to find among northern pools where dredging requirements and recreational use are both generally higher. Natural variability in drawdown depth due to variation in discharge will be an important element of analyses in these pools.

- Treatment pools should have few confounding effects from other management actions or from unusual features (e.g., dam height at Pool 19, Lake Pepin in Pool 4). If other management actions are being applied in treatment pools, they should have minimal effects on drawdown responses, or be consistent among design pools, or be easily separated from the effects of drawdowns.

- In southern reaches, some pools have historically had vegetation and some have not. We suggest that southern treatment pools should have a history of occurrence of emergent and submersed vegetation, if possible.

- Any candidate pools must have acceptable requirements for dredging and spoil placement, and for effects on recreation, water supply, archaeological sites, etc. As with previous drawdowns, it will be critical to involve stakeholders in the process of choosing treatment pools and developing drawdown plans.

<u>Characteristics for choosing reference pools</u>

For assessing drawdowns, a reference or control pool should be as similar as possible to the treatment pool(s). The reference pools should provide data on background variability and large scale directional trends. No management actions should be conducted in the control pool that would confound or bias evaluation data. A control pool should be distant enough from the treatment pool to represent a quasi-independent sample, i.e., it should not be affected by events in the treatment pool and individual organisms should not move between both pools. This is likely valid for vegetation (in the year of drawdown), adult mussels, immature aquatic insects, and sedentary fishes. However, it may not be true, especially in years following the initial drawdown, for migratory fishes, birds, or plants and animals whose progeny (seeds, larvae, juveniles, etc.) are dispersed by wind, water, or birds. However, a control pool should not be so distant from the drawdown pool that longitudinal variation in biota or environmental variables is significant. These conflicting criteria occur in the UMR and in general support selecting, as a compromise, a control pool that is 2-3 pools upriver from the treatment pool. A pool immediately downstream from a treatment pool could be directly affected by materials discharged from the treatment pool and should be avoided as a reference pool.

LTRMP focal pools might be considered for controls if their location relative to treatment pools is appropriate. Even if LTRMP pools are not controls, data from these pools continues to provide insight into background variation along the environmental gradient of the river and potential systemic changes.

<u>Opportunities for focused studies to provide additional information</u>

Within the adaptive management framework we propose, there may be focused studies that can provide information on mechanisms for the effects of drawdowns or on why expected effects were not observed. This work could be conducted by NESP partners or by other agencies or academic institutions. Opportunities for such studies should be considered as long as they do not compromise the integrity of the overall experimental design. These results can be used along with monitoring data to help inform revisions to the adaptive management design. Examples of potential studies include:

- *Seed bank evaluation.* A seed bank study was conducted in northern pools (Kenow and Lyons 2009) and indicated that seed bank did not limit the response of annual or perennial plants. A similar study in Pool 18 (unpublished data, Amber Andress, U.S. Fish and Wildlife Service, Rock Island, Illinois) indicated that seeds of submersed aquatic plants were scarce. A seed bank study in lower pools (e.g., 24, 25, 26) may provide useful information for comparison to the drawdown results seen in Pool 25.

- *Modeling expected variation in water levels at mid-pool and dam during a drawdown*. This information may help in choosing treatment pools or may help in applying knowledge gained from treatment pools to other pools.

- *Relation of ground water elevation to surface water elevation.* Ground water elevation may be critical for understanding terrestrial responses, but is difficult to measure directly at large scales. Modeling ground water levels based on surface water may be much more efficient.

- *Planting to "jump start" vegetation responses*. If some expected vegetation responses are not evident, but environmental conditions seem appropriate, we may want to imbed focused research to "jump start" vegetation by hand planting emergents, submersed, or forest trees in experimental plots to compare to areas without planting.

- *Modification of conditions to elicit vegetation responses*. If vegetation responses are not evident, especially for aquatic vegetation in southern pools, we may want to imbed experiments within treatment pools aimed at improving local conditions for plant growth. This could include exclosures to reduce herbivory, or building islands to create pockets of quite water with lower turbidity. Such studies may help determine the causes for specific responses or lack of response.

The experimental designs described above should create the conditions and comparisons needed to learn about critical questions and effects of drawdowns. However, an effective monitoring plan is also needed to provide the information that can answer those questions. In the next chapter, we discuss monitoring approaches and recommendations for learning.

CHAPTER 4. Monitoring and Evaluation Applied to the Drawdown Experimental Designs

The conceptual models for drawdown effects (Figs. 5-10) suggest many possible components and variables that could be monitored or evaluated. As part of developing the specifics for implementing an experimental design, managers will need to determine the priority questions to be addressed and monitoring strategies needed. We suggest that, given current knowledge, uncertainties, and stakeholder concerns, the most critical elements for monitoring relate to determining mechanisms that affect long-term dynamics of aquatic vegetation, mussels, and fish. Beyond these components, some level of monitoring related to long-term effects on forest communities would help determine if repeated drawdowns can affect forest composition and may suggest ways to modify the experimental design or monitoring plan for increase learning potential. Below we describe a general approach to determining monitoring variables and provide examples related to the proposed experimental designs.

The types of monitoring required to evaluate drawdowns on the UMRS are best understood through the general conceptual model (CM) for UMRS restoration (Fig. 4). The CM includes both "Natural Drivers" (left side) and "Socio-Economic Drivers" (right side) to reflect the duality of the NESP program vision. The CM (Fig. 4) provides an organizing template for delineating different critical ecosystem components (Essential Ecosystem Characteristics, EECs) and postulating the strength of their interactions. The EECs summarize the most important attributes of the UMRS ecosystem and the interactions among EECs can be used as a heuristic to guide understanding of the dynamics of the UMRS.

Highlighting the EECs emphasizes the need to identify in advance the response variables and their specific measures critical to learning about drawdowns. Considerations of required accuracy and precision for each response variable are needed for an effective monitoring program. The desired data quality for any given measurement may be determined by (1) current understanding of spatial-temporal variations associated with the measurement, (2) the availability of resources for monitoring, (3) the quality of the data needed to make a management decision, (4) the benefits of correct management decisions, and (5) the consequences of incorrect decisions.

The EECs provide focal points for development of parts of a monitoring program for water level management. EECs are derived by grouping the large number of potential variables that each could contribute to defining ecosystem state into like categories. For example, variables that define patterns in stage or discharge and hydraulic variables that are used to calculate transport, material loadings, or shear forces are grouped into an EEC "Hydrology and Hydraulics". The other four EECs determined for the UMRS are Geomorphology, Biogeochemistry, Biota and Habitat (Fig. 4). In addition, the CM can be hierarchically stratified into three, nested adaptive management cycles (Fig. 11) each supported by a specific type of monitoring.

Three Categories of Monitoring

Lyons et al. (2008) identify three categories of monitoring variables - ecosystem status variables; report card variables; and learning variables - that should be considered in Adaptive Management for restoration. These three categories are germane to drawdowns and are represented in the nested cycles of adaptive management (Fig. 11). These three categories are elaborated below as they relate to monitoring of an experimental design for drawdowns.

Ecosystem status variables

Definition: Status variables describe the condition of a part of the ecosystem (e.g., project, sub-pool, pool) through the lens of one of the EECs. They are used to determine if restoration is required, to develop a broad outline of potential restoration measures, and to determine responses to management actions. They are typically associated with the intermediate cycle of adaptive management (Fig. 11) and can be interpreted by an audience comprised of scientists, managers, and stakeholders.

Form: Status variables are typically snapshots in time that are often summarized as means and ranges over relatively large temporal (e.g., months, years, decades) and spatial scales (e.g., project, sub-pool, or pool).

Sampling Investment: Sampling investment for different variables is based on an *a priori* evaluation of uncertainty. Actions for which environmental benefits are relatively certain require lower levels of sampling so that sampling investment can be focused on more uncertain actions. Sampling investment is partially determined by the spatial scale (i.e., stratification) and temporal regularity of sampling.

Temporal Sampling Investment: The temporal scale of sampling will be dictated by the inherent temporal pattern of the variable monitored. It is important to completely describe the physical domain affected by management action from pre-action status to a new post-action equilibrium so that sufficient information is available to guide management action. Some examples of how sampling duration can be affected by differences in temporal dynamics include:

- Flow distribution between the main and secondary channels changes over days and weeks, so average daily means may be required.
- Flood plain forest types my change over months or years, so that monthly or annual sampling may be adequate.
- Different types of response curves, such as, positive response followed by senescence/decay, negative response followed by a positive response, or lagged responses (Fig 12).

Spatial Sampling Investment: The spatial scale of sampling will be dictated by inherent spatial patterns among and within pools. For example, in Pool 5-9, analyses indicate a longitudinal pattern within pools comprised of three separate areas: upper, middle, and lower pool (Fig. 13).

Sampling in large rivers is difficult because of their large spatial scale and high spatial variability. Simulation modeling can be used to determine the spatial pattern of key variables, which can then be used to stratify within-pool sampling to reduce sample variance. Model output should be evaluated to search for zones within the pool where values of variables tend to be uniform over large spatial areas as water levels change.

Decision Points: Decision points for status variables are often associated with known points in the monitoring plan (e.g., end of pre-project monitoring, end of an iteration loop), generation of new information required to answer critical questions, achieving specific target levels for variables, or surprises in responses (e.g., unexpected negative outcomes). When any of these decision points is reached, managers should reassess their situation and determine if changes are needed in the experimental design or monitoring plan. Managers should assess decision points at regular intervals until the evaluation is completed, that is, when critical questions have been answered or when target levels for specific variables have been reached.

Examples: Data collected through the Long Term Resource Monitoring Program form the backbone of ecosystem status variables collected for the UMRS. Similar types of data collection may be appropriate for some variables in treatment and control pools. However, because of the specific focus of the experimental design on drawdown effects, sampling would likely not involve the full extent of LTRMP designs. Ecosystem status variables may make a modest contribution to the learning about process and function through analyses of changes in structure (community structure, age structure, channel characteristics, etc.). However, natural variability can make it difficult to obtain statistically significant results. Examples of ecosystem status variables applied to evaluation of an experimental design for drawdowns include:

- Flows, flow patterns, and water elevation
- Sedimentation rates in the main channel and dredging needs
- Turbidity levels and spatial patterns within pools
- Abundance and distribution of aquatic plants, native mussels, fishes, and forest communities (total and/or by species). Abundance measures could include numbers, density, biomass, use days, etc,
- Human use of pools for fishing, bird watching, camping, etc.
- Nutrient and carbon inputs to, and export from, the pools

Report card variables

Definition: Report card variables are aggregate variables used to communicate to stakeholders, legislators, or administrators the effectiveness of management actions or significant findings that address critical questions. They often connect the left and right sides of the general CM (Fig. 4) and translate findings from status and trends variables or learning variables into lay terms. Report card variables often address goals and objectives developed on the socio-economic side of the CM.

Form: Typically, report card variables summarize information over broad time and space scales. They are often presented as the quotient of present state relative to a future goal or endpoint, and in graphical or map-based representations. In the evaluation of effects of drawdowns, report card variables may also be expressed as answers to specific questions posed in the specific conceptual models or as general levels of improvement or decline (trends) over time.

Sampling Investment: Report card variables typically have little or no sampling investment because they are primarily modifications or summaries of variables obtained primarily from other monitoring. Primary investments will occur to integrate information from other sources (e.g., status variables) and to educate stakeholders on their appropriate interpretation. Use of standard protocols for all data collection efforts will help considerably to facilitate summarizing data into program-level descriptions.

> *Temporal Sampling Investment:* The temporal scale of report card variables is dictated by reporting requirements (e.g., reports to Congress) or by milestones associated with major projects. For reporting progress over time, report card variables are typically reported over coarse time intervals (e.g., monthly, seasonally, yearly) so that time trends associated with management actions are apparent. Ideally, reports of progress should begin with conditions prior to the restoration action and present additional information at regular intervals or at critical points in program activities such that the benefits and any unanticipated effects of restoration actions are clearly described.
>
> *Spatial Sampling Investment*: Report card variables often cover large spatial scales because they consolidate and summarize information for large areas (system, reach, administrative units, pools, etc.). However, when report cards are used to communicate answers to critical questions, they will represent the spatial scale of the questions, such as differences in ways to apply restoration techniques in upper versus lower reaches of the river.

Decision Points: Decision points for Report Card variables often come at the end of the project and relate to overall success and next steps. Report card variables are generally too coarse to adjust individual management actions, but may be used to reprioritize major program-level investments among locations or among different management actions. The end-points defined from ecosystem status variables can also be rolled up to create system-level end-points that gage the overall efficiency of program execution.

Examples: Report card variables for drawdown evaluation will summarize information related to the major treatments and questions addressed. Examples include:

- Measure of the degree to which summer water levels during drawdowns approximate historical conditions and the number of river miles affected.
- Comparisons of trajectories of response variables over time for different drawdown frequencies.
- Comparisons of how variables respond in northern versus southern reaches, and of different mechanisms involved, different objectives needed between reaches, or different options for conducting drawdowns to achieve success in each reach.
- Comparisons of indices of mussel community health among treatment and reference pools

Learning variables

Definition: Learning variables typically focus on process and function, or cause and effect relations. They are associated with the research level of adaptive management (Fig. 11) and are aimed at reducing scientific uncertainty to support effective decision-making. An understanding of processes allows managers to determine the most effective way to modify management actions to achieve program goals, or to apply those actions in other parts of the system. Effective monitoring of learning variables is critical in adaptive management because they provide the information used for the next iteration of decision-making. Judicious use of learning variables can help reduce the number of iterations needed, resulting in more economical program management. The importance of the learning variables to effective decision-making may not be immediately clear and it may require explanation to emphasize their importance to a lay audience..

Form: Learning variables can often be identified by examining the relations described in the component-specific conceptual models. These variables represent rates, dynamics, time dependencies, limiting factors, etc. that can control processes. They may also represent model assumptions that are untested. Many learning variables occur at the interfaces among EECs (Fig. 4).

Sampling Investment: Learning variables must be sampled at their inherent scales, which are often small. Monitoring algal uptake of nutrients at monthly intervals provides little understanding of the process because algal nutrient uptake typically occurs at scales of minutes. Thus, rather than broad sampling of learning variables, it is often more efficient to focus more intense effort at smaller scales. To be of greatest utility, learning variables should address processes that control the dynamics of critical status variables.

> *Temporal Sampling Investment:* The temporal scale of sampling will be dictated by the inherent temporal pattern of the variable(s) in question. For example, hydraulic characteristics in channels change with discharge so average daily means of discharge may be required. In contrast, learning about behavior and mortality rates of mussels in exposed areas will require more intense study during the drawdown, whereas mortality

rates of mussels in deep areas are probably fairly consistent over time so sampling at annual or longer periods may be adequate.

Spatial Sampling Investment: The spatial scale of sampling will be dictated by inherent spatial patterns among and within pools that dictate where required data can be collected most effectively. Typically, intense sampling within a limited spatial domain is more likely uncover the relationship among different variables, than is sampling over spatial scales that are larger than the scale of the process. Simulation modeling can sometimes be used to suggest the most appropriate sampling scales for variable that are poorly studied.

<u>Decision points:</u> Decision points for learning variables are typically defined by statistical analyses that determine when a target relationship has been defined or an assumption evaluated, to an appropriate level on certainty. Ideally, that level of certainty should be determined *a priori*.

<u>Examples:</u> Learning variables for evaluating drawdowns should be related to processes that control the primary status variables: aquatic vegetation, mussels, fish, and forests. Examples include:

- Turbidity levels and their spatial variation, especially as related to patterns in current velocity, wave energy, and aquatic plant distribution.
- Hydraulic processes and metrics in channels as related to discharge.
- Dynamics of dissolved oxygen in backwater areas during the drawdown and in winter in backwaters that experience increases in aquatic vegetation.
- Degree of variation in water levels relative to pre-dam variation and resulting effects on soil moisture and littoral and riparian biota.
- Rates of lateral water movement through soils and relation of surface water elevations to ground water elevations.
- Soil moisture and oxygenation in exposed shorelines areas and in the aerated zone of terrestrial soils.
- Adequacy of the seed bank in both aquatic and terrestrial areas.
- Germination and survival rates for forest tree species.
- Concentration of food resources in main channel drift.
- Rates of reproduction and juvenile survival (year class strength) of mussels, fishes, and forest trees.
- Movements and behavior of mussels in shallow and exposed areas relative to substrate slope, sediment characteristics, and variation in water levels.
- Mortality rates of mussels in exposed areas, and of adult mussels and fishes in aquatic habitats.
- Rates of recolonization of exposed areas by mussels and other invertebrates.

- Thresholds at which plants create alternative stable states, e.g., size of plant patches/beds, turbidity levels, flood frequency.

The monitoring examples suggested above for status, report card, and learning are not exhaustive, but focus on some of the critical elements for evaluating the drawdown experimental designs. There are certainly more possible monitoring efforts than funding and effort will allow. After specific treatment pools are chosen for the experimental design, managers must determine the component responses that are of primary concern to them. The details of sampling, including sample size, temporal and spatial extent, and analyses, must be determined through collaboration between managers, researchers, and statisticians in light of the information needs that are most critical and the funding and effort available. The discussions should include pre-project data needs, times when data analyses are required as input to decision points, and an expectation of the total time required for a full evaluation.

Implementing an adaptive management approach will require more monitoring and evaluation has been applied to most restoration projects (O'Donnell and Galat 2008). Managers should prioritize the information they want to generate and seek monitoring designs that are as efficient as possible. However, the return from monitoring ultimately comes in terms of more effective and less costly management in the future based on new knowledge.

Among the three types of monitoring variables, learning variables will require the most intensive monitoring. Hopefully, information gained about learning variables can help increase the efficiency of longer term monitoring by focusing on critical data that are most informative. For trend and report card variables, monitoring may be needed over long time frames (10-20 years), but intensity of collection (sample sizes and frequency) may be relatively low. Statisticians should be engaged in designing monitoring plans, including defining decision points, and in analyses of data and resulting modifications of monitoring plans over time.

Even with efficient monitoring plans, we realize that it may not be possible to fully implement the adaptive management designs we propose without increased levels of effort for river restoration and science. Some aspects of the designs can be implemented individually and information can be gained. But by implementing individual elements, direct comparisons of some design features will not be possible and the efficiency of the learning process will be compromised. However, some focused studies (see Chapter 3) could be conducted without implementing any drawdowns and would provide information to help with pool selection or monitoring plans to implement the adaptive management approach in the future.

Chapter 5. Reporting and Decision Making

To complete the adaptive management loop, new information gained from the leaning design must be communicated and incorporated into our knowledge base for drawdowns. This new information is then used to help determine the best options for using drawdowns to achieve desired outcomes under different conditions on the river.

Data Summarization and Decision Points

Chapter 4 suggests general time frames and decision points required for monitoring different effects of drawdowns. Managers and scientists will still need to develop these generalities into a specific, detailed monitoring plan. The plan needs to set the expected time frames for data collection (pre-project and post-project), times when data analyses and summaries are expected, any ancillary data (e.g., from focused studies) that are needed and by when, times when specific decision points will be reached, and the expected time to complete the first iteration of the adaptive management cycle (Fig. 11).

Data summarization and reporting that agree in form and content with management goals facilitate decision-making. Ideally, decision criteria should be discussed and determined before the project begins. Decision criteria are the quantitative values of the selected response variables that will cause continuation of the management action through another iteration, or a change or termination of the management action. The characteristics of the decision criteria can be used to develop the methods, content, and format for summarizing and reporting the information obtained from monitoring so that it feeds directly into the decision-making process. Managers and decision-makers will receive the exact kinds of information they need for effective decision-making.

There will likely to be many decision points within either of the two experimental design options suggested in Chapter 3. One obvious decision point is at the end of pre-project data collection. Assessments of pre-project data provide the baseline information for the project and allow managers to develop quantitative criteria that define success in answering the critical questions embodied in the design.

Another obvious decision point is the end of the first adaptive management iteration. At that point, managers must assess monitoring data, and any other ancillary data sets generated, to determine the most appropriate next steps. Potential next steps at the end of the first iteration include:

- Continue with an additional iteration to develop a more robust data set if conclusions cannot be reached,
- Continue, but redesign the project or monitoring plan to provide better or different data in a second iteration,

- Develop new questions to be addressed in another iteration,
- Declare success in answering the question, then move forward to incorporate what's been learned into standard management procedures, or
- Return to previous water level management practices if unexpected negative effects are unacceptable.

As indicated in Chapter 3, time frames for iterations and decision points will differ among the three levels of frequency treatments suggested in the two experimental design options. The questions that will likely require the longest time to answer are probably those related to whether the system can be shifted into an alternate stable state for aquatic vegetation or for forest diversity.

Although expected time frames should be identified before the project begins, another hallmark of adaptive management is the need for flexibility in decision making, both administratively and scientifically. Unanticipated variation in natural system drivers, in funding, or in the time required to generate needed data, can all throw time tables off track and require modification of the experimental design, the monitoring plan, or the expected dates for reporting and project completion. Agency procedures need to be flexible to allow for modifications to projects plans in ways that can overcome obstacles without compromising the ability to achieve project goals.

Reporting Progress and Improving Management Capabilities

The nature of data summarization and reporting will be determined in part by the intended users of this information. Different reporting formats (e.g., tables, graphs, maps, GIS presentations, animation, written or verbal summaries) will be appropriate if the same information serves different user communities (e.g., scientists, managers, regulators). Statistical reporting will be of interest for learning variables. Statistical summaries and reporting are also essential for quantitative comparison of status variables over time or space, or with predicted values. These summaries should include some description of precision of the data and of statistical significance, when appropriate.

Less rigorous data summarization might be sufficient to report general trends, changes in condition, or project performance to a lay audience. At the same time, some discussion of the accuracy and reliability of the data and information should accompany reports to this audience.

An effective data summarization and reporting program can help to improve monitoring capabilities. Summarization of data derived from learning may provide insights to relationships that can be used to apply these management actions in other times and places. Through this process, learning variables can become routinely monitored response or status variables and their anticipated values can be applied as decision criteria for future management actions. The accumulation of well-described learning variables can also be used to develop new management goals and objectives for future management actions.

No project will exist very long if it creates a “black hole” of project information while waiting to produce the final report. This is especially true in adaptive management, which requires stakeholder engagement and assessment of progress at frequent intervals. Different response variables will likely be sampled at different frequencies. Thus, in addition to reports produced at expected intervals, data and information on project status should be reported regularly to interested parties to keep them engaged and updated on progress. This serves to keep new information available to stakeholders at more frequent intervals and helps them to see a body of data developing that will result in better understanding and, ultimately, better management decisions. However, these reports must also indicate when data are insufficient to reach conclusions and provide some expectation of when, or under what conditions, conclusions can likely be made.

To make adaptive management projects most useful, all data, information, and products produced should be readily available to all interested parties. We suggest that the Decision Support System currently being developed under NESP be used as the primary repository and access point for this new information.

The application of adaptive management outlined in this report will only be effective if the full loop is implemented. Each decision point and each iteration loop is an opportunity to develop more effective decision making. The development of decision points and criteria, and of a plan to incorporate new information into future decision-making, must be agreed to by agency administrators and program managers. It is critical that they be kept informed of, and dedicated to, progress of the project.

Chapter 6. Summary of Conclusions and Recommendations

Water level drawdowns during summer on the UMRS have produced some desirable ecological results. However, a number of key questions regarding implementation and effects remain. All indications are that managers will continue to use drawdowns on the UMRS. If a subset of those drawdowns can be conducted in a manner specifically designed to address critical remaining questions, managers can increase their understanding of how drawdowns affect ecosystem processes and outcomes, and make better management decisions. Our goal in this report is to provide an approach that can produce an efficient learning process, a hallmark of effective adaptive management.

Our conclusions and recommendations regarding this approach are:

1. Modeling is recommended as a critical part of adaptive management, and can include conceptual constructs, simulation/numerical constructs, or both. Models provide a vehicle for expressing current knowledge about how a system functions. They serve to document current understanding and uncertainties, and provide a concise way to communicate that information among stakeholders. Predictions and perspectives from modeling can be tested in the field to help determine the effectiveness of drawdowns at achieving specific management objectives. These models (Chapter 2) should be updated in the future as new information leads to a better understanding of these relationships and effects.

2. The design for study and experimentation to address significant questions and uncertainties regarding drawdown effects (Chapter 3) should derive from the specific conceptual models presented in this report (Figs. 5-10), and the overarching UMRS model developed previously (Fig 4).

3. Incorporating pools from northern and southern reaches into the study design (Chapter 3, p. 18) is critical to learning about how drawdowns function under the different environmental conditions encountered within the UMRS.

4. The frequency of repeated drawdowns is a critical question that needs to be addressed by an adaptive management process. More frequent drawdowns may cost more, but there may be desirable long-term gains from frequent drawdowns. We encourage consideration of two potential options for including frequency in an experimental design to address the ecological effects of drawdowns (Chapter 3).

5. While implementing an adaptive strategy for evaluating effects of drawdowns, undesired responses may result. Such responses should be quickly countered to avoid unnecessary additional costs or potential damages to the system. When implementation of the design has provided sufficient information to answer critical questions, the design can be modified, including a return to standard dam operation (Chapter 3).

6. Experimental treatment pools must be selected carefully, with consideration given to (a) specific implementation requirements identified to perform the planned management actions and (b) economic costs and social effects of implementing proposed actions (Chapter 3).

7. When specific treatment pools are chosen for the experimental design, managers must determine the major responses that are of primary concern and those that need not be evaluated. The details of monitoring, including sample size, spatial extent, and analyses, should be determined through collaboration among managers, researchers, and statisticians (Chapter 4).

8. For assessing the effects of drawdowns, reference pools should be as similar as possible to the drawdown (treatment) pool(s), and unaffected by events in the treatment pool(s). The reference pool(s) should provide data that quantify background variability and large scale directional trends during the study period for comparison to the treatment pools (Chapter 3).

9. Along with pool-scale adaptive management experiments, more localized and focused studies may be needed to provide information on specific mechanisms underlying effects observed in pool-scale monitoring (Chapter 3).

10. Monitoring for learning about drawdowns should be based on critical questions derived from conceptual modeling. Monitoring for learning should emphasize environmental processes and cause-and-effect relations. Variables monitored should provide information on both structure and function of the UMRS, to help better identify mechanisms that underlie drawdown responses (Chapter 4).

11. Given current knowledge, uncertainties, and stakeholder concerns, we suggest that the most critical elements for monitoring relate to determining mechanisms that affect long-term responses of aquatic vegetation, mussels, and fish to drawdowns. In addition, monitoring of long-term

effects on forest communities would help determine if repeated drawdowns can affect forest composition and community dynamics (Chapter 4). For mussels, fish, and forests, monitoring effects on early life stages should provide information more quickly than concentrating on adults.

12. Information derived from monitoring must be incorporated into new decisions about next-steps in the experimental design and ultimately, into management policies. The process and expected schedule for reporting monitoring results and for decision points should be identified in project planning documents (Chapter 5).

13. Adaptive management requires flexibility in decision making, both administratively and scientifically, to account for variation in system drivers, in funding, or in the time required to generate needed data. Agency procedures need to be flexible to allow for modifications to projects plans in ways that can overcome obstacles without compromising the ability to achieve project goals (Chapter 5).

14. We suggest that the Decision Support System currently being developed for the UMRS be used as the primary repository and access point for new information from water level management and other approaches for achieving ecosystem restoration goals and objectives (Chapter 5).

Applying this Approach to other Management Actions

The process we used in developing this initial adaptive management plan for drawdowns can be applied to virtually any management actions on large rivers. The approach could be applied to other management techniques (e.g., fish passage, side channel restoration, floodplain restoration, etc.), or could begin with broad management objectives, then assess multiple techniques to learn more about which techniques, performed singly or in combination, are most effective at achieving those objectives. The basic steps in the process are:

- review management issues and current knowledge,
- develop corresponding conceptual models,
- use the models to define critical questions and key uncertainties, and
- develop treatments and experimental designs for field studies that address priority questions.

If the resulting design is implemented, additional work is needed to:

- choose locations for applying treatments
- develop monitoring plans, and
- develop schedules for data analyses, decision points, and reporting.

Our application of this process to summer drawdowns began with a considerable amount of data and information derived from pilot studies and demonstration projects. An application to management actions for which we have little or no experience on the UMRS (e.g., fish passage, side channel restoration, floodplain restoration) may require more extensive designs. Alternatively, an analysis of the issues may suggest small pilot projects, similar to the approach taken initially with drawdowns, to provide better information for developing a larger-scale adaptive management approach.

The UMRS offers substantial opportunities for developing new understanding about how large rivers function and about managing for both social and ecological outcomes. The characteristics that contribute to this capability are unmatched in other large river systems and include gradients of ecological and social conditions within the system; the replicated nature of many of the engineering and ecological features; the existing data bases; the concentration of regional expertise within agencies, academic institutions, and non-governmental organizations; the cooperation among agencies and stakeholders; and an ongoing rehabilitation program. These characteristics provide unique opportunities for learning through adaptive management that can lead to more effective management of the UMRS and other large river systems.

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Table 1. Primary relations and effects for different system components, and uncertainties related to those effects, as derived from the conceptual models developed by the authors and regional experts for summer drawdowns on the Upper Mississippi River System. "Likelihood" refers to the level of confidence that the effect will be realized.

Component and Effect	Likelihood of effect	Comments	Questions or Uncertainties
Ecological processes			
Lower water level exposes and dries shallow areas. • Lowering of ground water table • Aeration of sediments and compaction in areas high in organic matter.	 High High	Occurs only during drawdown. Emulates natural summer conditions. Has direct effects on soil chemistry and plant germination. Extent of exposure varies as discharge changes. Sediment particle size composition will influence degree of compaction.	Do differences in short-term (daily to weekly) variation in water levels, within a pool or between pools, correlate with differences in biotic responses? What degree of short-term water level variation creates optimal habitat diversity?
Decreased water volume in pool. • Increased percentage of flow in major channels with increased current velocity and sediment transport. • Increased retention time in off-channel areas. • Increased variation in dissolved oxygen and higher temperatures in backwaters.	 High Medium Medium	Occurs only during drawdown. Creates more natural (historical) conditions of flow distribution and velocities.	Will substantial changes in patterns of sediment erosion and deposition occur? • Will tributary mouths and deltas erode? Will changes in dissolved oxygen levels and temperatures in backwaters affect the abundance of plants, invertebrates, and fish in those locations? Will increased biomass of dead aquatic plants in winter increase oxygen demand and reduce oxygen levels in backwaters?
Reduced water levels allows light to penetrate to the bottom in areas previously too deep (shifted littoral zone).	Medium	Occurs only during drawdown. Effect depends on water transparency. May increase benthic algae growth and sediment stability.	Will this effect be significant in areas with high ambient turbidity (e.g., lower impounded reaches and Illinois River)?

Nutrient cycling will be modified by changes in sediment chemistry, oxygen dynamics, temperature, storage in plants, and rates of organic matter decomposition (especially for aquatic plants), and may reduce pool-wide export.	Low	These individual changes are likely to occur, but many of these effects and their interactions are non-linear and very difficult to predict, making pool-wide effects uncertain.	Does incorporation of nutrients into plants result in long-term storage of nutrients? Will nutrient retention rates within a pool increase or decrease during a drawdown? Are there long-term effects on nutrient dynamics from multiple drawdowns?
Vegetation			
Exposure of shallow areas: • Stimulates germination of seeds for emergent and terrestrial plants. • Eliminates growth of submersed aquatic plants in exposed areas.	 High High	Occurs only during drawdown. Stimulates natural processes that where common under the historical hydrograph.	What is the response curve of abundance of vegetation to repeated drawdowns? Ho w long will increased abundance of emergent vegetation persist after returning to standard water level management? How can we promote perennial rather than annual emergent plants, especially in lower river pools? Is seed bank sufficient in lower river pools? Will drawdowns favor native species over exotics? What level of aquatic plant abundance is enough, or too much?
Light penetration to substrates in offshore areas formerly too deep (shifted littoral zone) promotes growth of submersed vegetation in those areas.	Medium	Occurs only in years of drawdown. Response depends on water clarity.	Will growth of submersed vegetation in offshore areas continue after returning to higher water levels? Will herbivory (by fish, reptiles, or mammals) in lower pools reduce or eliminate a submersed plant response?

Sediment consolidation and increased abundance of vegetation reduces shoreline erosion and sediment resuspension from shorelines and shallow areas. • Water clarity increases.	Medium Low	Occurs after plants are established during drawdown and in years following drawdown if plants persist. Local responses in sediment resuspension and water clarity will depend on factors such as ambient turbidity, wind fetch, sediment type, and water depth.	Will water clarity increase in pools with high ambient turbidity (e.g., lower pools)? • In pools in lower reaches, will water clarity increase in areas that are sheltered from current (connected backwaters, area downstream of islands, etc.)? Will increased water clarity and increased retention time of water in off-channel areas or plant beds increase production of phytoplankton? Will repeated drawdowns create a new zone of shoreline erosion and reduced plant growth at a lower elevation?
A combination of the effects of increased vegetation, reduced shoreline erosion, reduced sediment resuspension, and increased water clarity and may reinforce each other, resulting in positive feedbacks that create a condition dominated by aquatic macrophytes in shallow areas that is self-sustaining under standard water level management (an alternate stable state).	Low	This would restore conditions that existed previously at many locations within the UMRS. Although we expect many of these individual effects to occur, a strong interaction among them is needed to convert the system to an alternate, macrophyte-based, stable state.	Can we implement drawdowns in a manner that promotes and maintains an aquatic-macrophyte-based stable state? • What factors contribute to persistent macrophyte beds that already exist in the UMRS? In southern pools, are ambient turbidity or short-term water level variation too high to allow this shift? Would a macrophyte-based stable state produce more aquatic plant biomass than is desired by river users?
Lower water table promotes growth of terrestrial vegetation that prefers dryer conditions. • Diversity of forests and other terrestrial vegetation increases.	Low Low	Occurs only in years of drawdown. Emulates natural summer conditions. Change in communities requires long term survival of plants that prefer dryer conditions.	Will multiple drawdowns produce change in terrestrial vegetation, including more diverse forest communities? Will distribution of wetlands change? Will non-native plants out-compete natives?

Mussels			
Exposure of shallow areas causes increased mortality of native mussels. • The proportion of the mussel population in shallow areas decreases.	High Medium	Occurs only during drawdown. Emulates natural summer conditions. After an initial drawdown, this effect is likely reduced in repeated drawdowns as fewer mussels inhabit shallow areas. Mussels may use behaviors (e.g., moving offshore, burrowing) that reduce mortality rates in exposed areas.	What are mortality rates of mussels in exposed areas? What proportion of mussels in shallow areas move to deeper offshore areas? Do mussels repopulate shallow areas after the drawdown ends?
Mortality of zebra mussels by exposure should reduce numbers attached to native mussels and increase native mussel survival.	Medium	Occurs only during drawdown.	Will concentration of water in primary channels during drawdowns affect the distribution of zebra mussel veligers and increase zebra mussel abundance in channels?
Current velocity will increase in major channels, which increases hydraulic forces and removal of waste products, especially during low flows, providing better habitat.	High	Occurs only during drawdown. Creates conditions more like the natural river historically.	Does mussel abundance increase in channels, or decrease in off-channel and impounded areas after multiple drawdowns? How do lower water levels and changes in current velocity affect transport, settling, and survival of juvenile mussels?
Increased current velocity, reduced water volume, and increased plant abundance should increase food concentration and delivery for mussels.	Low	Occurs mainly during drawdown, but increased plant or plankton abundance could produce longer term effect.	Is the concentration of particulate food resources (e.g., organic matter, plankton) in the main channel higher during a drawdown, and does this persist in succeeding years without a drawdown? Is growth rate or health of mussels in the main channel related to concentration of food resources?

Reduced water volume concentrates fishes and may make fish hosts more available to mussels, increasing reproduction.	Low	Occurs only during drawdown.	Does year class strength of mussels increase in the year of a drawdown?
Other Benthic invertebrates			
Exposure of shallow areas causes increased mortality of benthic invertebrates, including zebra mussels.	High	Only during drawdown. This effect may decrease with repeated drawdowns if these areas are not recolonized.	How quickly do invertebrates re-colonize shallow areas after they are reflooded? Is community composition different after a drawdown?
Increased abundance of aquatic plants (emergent and submersed) increases surface area and food resources for invertebrates and increases their abundance.	High	Occurs as long as aquatic plant abundance is increased.	
Increased current velocity should increase food delivery for invertebrates in the main channel and promote growth and diversity.	Low	Only during drawdown.	Does food limit benthic invertebrate production?

Fish			
Increased abundance of aquatic plants increases cover and invertebrate abundance, which increases fish survival, growth, and abundance.	High	Occurs as long as aquatic plant abundance is increased.	Does fish abundance (total or species specific) increase as vegetation abundance increases? Does fish community composition change after multiple drawdowns? Will this effect occur if plant response is primarily annual emergents (as is typical in lower reaches)? Will increased biomass of dead aquatic plants in winter reduce oxygen levels in backwaters and increase fish mortality?
Exposure of shallow areas may expose nests, reducing hatching success and year class strength.	Low	Occurs only during drawdown. Emulates natural conditions in early summer. Degree of effect will depend on timing of nesting and drawdown.	Is year class strength of littoral fishes reduced in years with a drawdown? Does the timing of starting a drawdown affect year class strength? Can compensatory increases in survival negate the effects of reduced hatching success?
Reduced water levels in backwaters increases fish density and may strand fish in newly isolated areas during the drawdown increasing predation rates and mortality.	Medium	Occurs only during drawdown. Probably similar to historic conditions. Increased feeding by wading birds was observed with drawdowns, but few mass mortality events were evident. Slow rate of water level reduction reduces the likelihood of stranding.	Are any mass mortality events of fishes evident in backwaters?
Birds			
Reduced water levels and exposed substrates will increase food availability for shorebirds and wading birds, increasing their abundance.	High	Occurs only during drawdown. Emulates natural summer conditions.	

Increased abundance of aquatic plants increases cover and food resources (plant & invertebrate), which increases migration fitness and reproductive potential of waterfowl.	High	Occurs as long as aquatic plant abundance is increased.	Is energetic fitness of waterfowl increased in years with increased vegetation abundance? For waterfowl nesting locally, does hatching and brood rearing success increase in the year of a drawdown?
Increased diversity of terrestrial forests will increase diversity and abundance of song birds and neo-tropical migrants.	Low	Occurs only if there is a response in forests.	

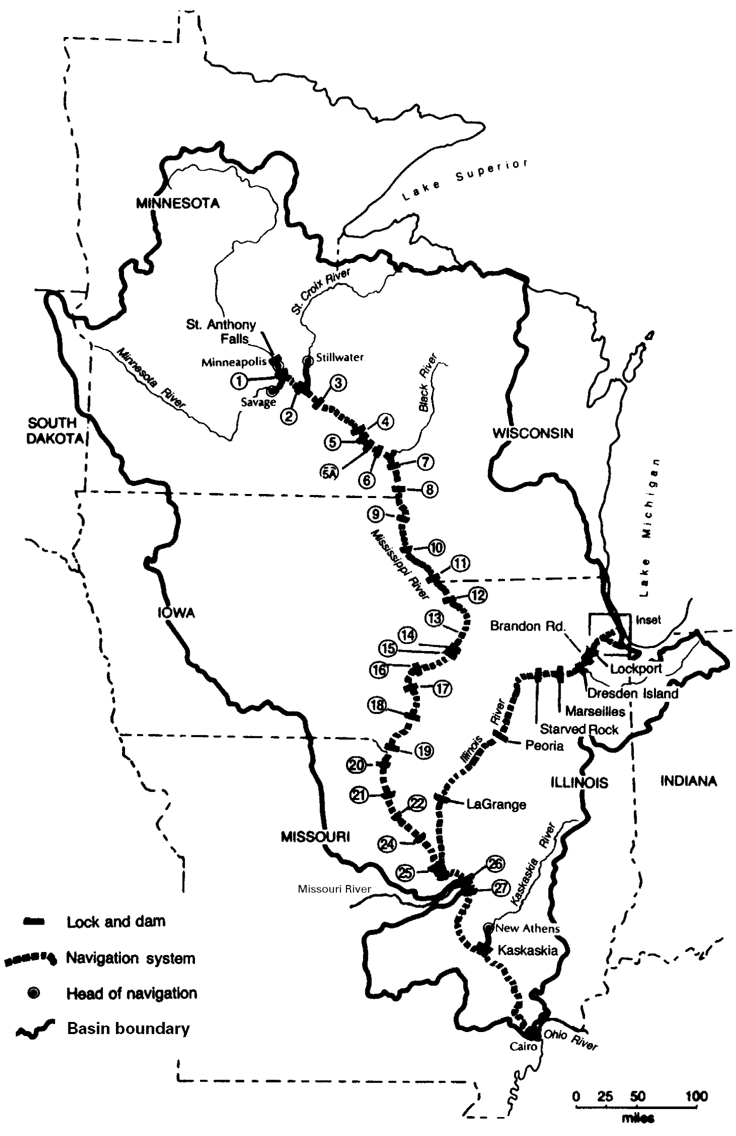


Figure 1. Upper Mississippi River System and its basin showing location of dams and their assigned number or name.

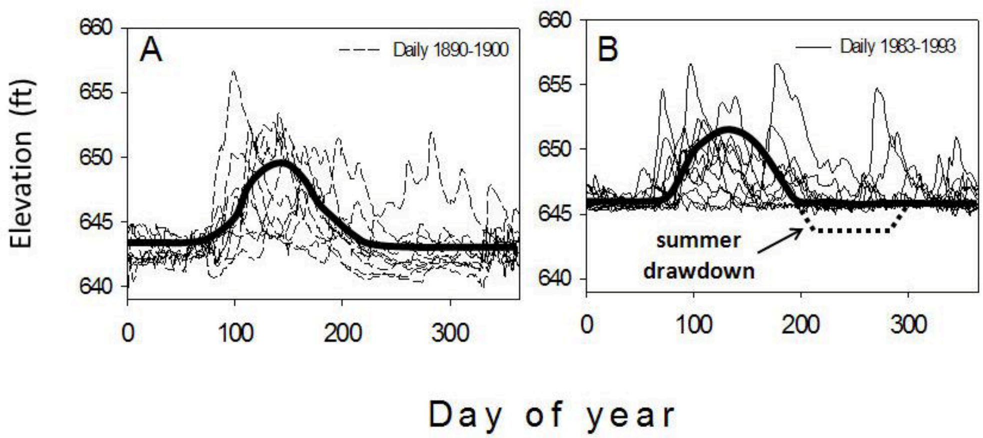


Figure 2. Daily water elevations (feet above mean sea level) on the Upper Mississippi River at Winona, Minnesota, from (A) 1890-1900 (before dam construction) and (B) 1983-1993 (after dam construction), and the mean daily elevation (heavy lines). Post-dam data show the increase in water elevation, mainly during low-discharge periods from summer through winter. The dashed line in 1983-1993 indicates potential water elevations during a summer drawdown.

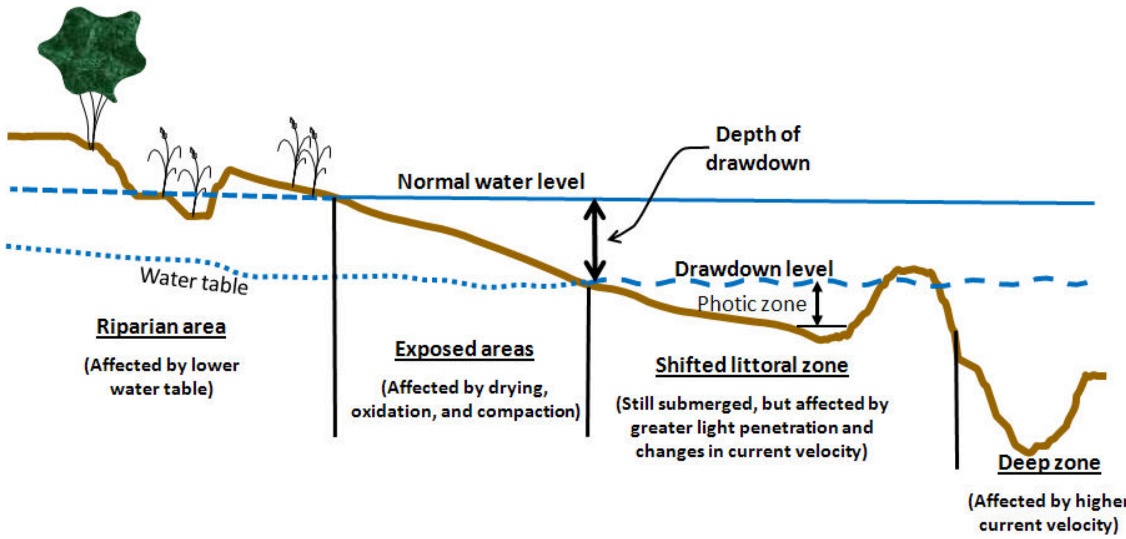


Figure 3. Cross-section of a shoreline transect showing four different zones for response during a drawdown.

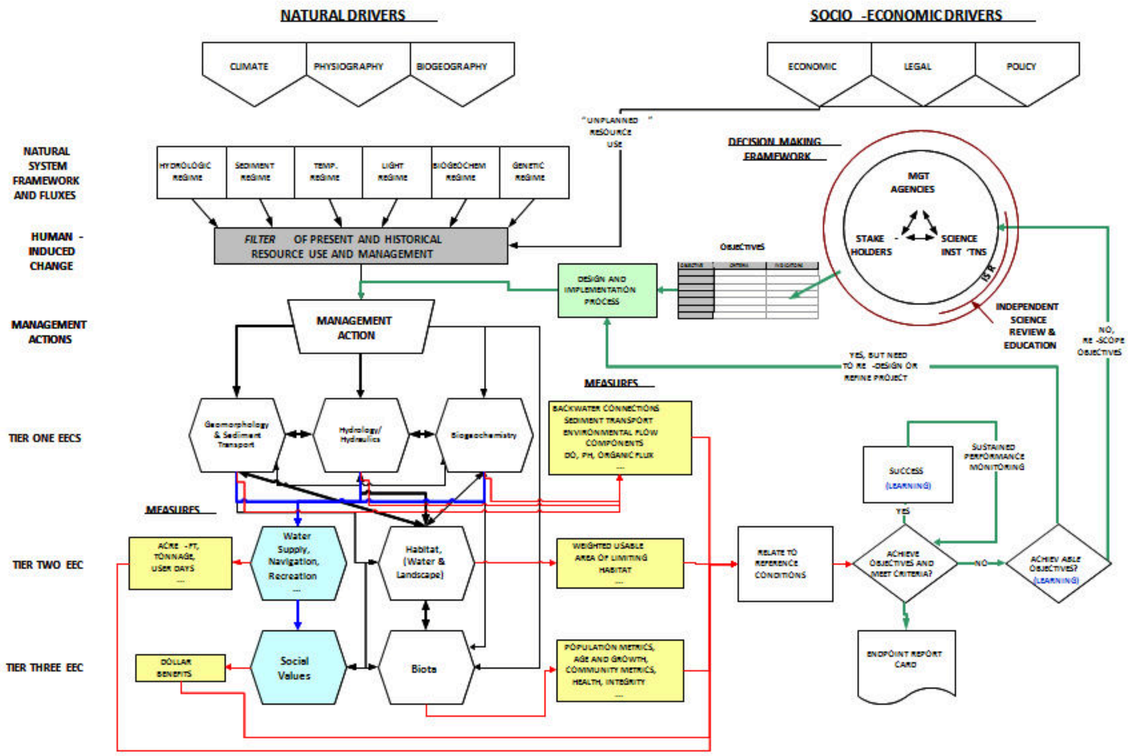


Figure 4. General conceptual model for the Navigation and Ecosystem Sustainability Program illustrating broad environmental relationships, socio-economic structure, and their linkages. Types of monitoring needed to execute the model are defined as follows: system status – summary of the status of each Essential Ecosystem Characteristic; learning – description of the dynamics among Essential Ecosystem Characteristic; report card – general rollup of system status monitoring used for program performance assessment and governance. Source: Lubinski and Barko 2003; revised by R. Jacobson and D. Galat, 2008.

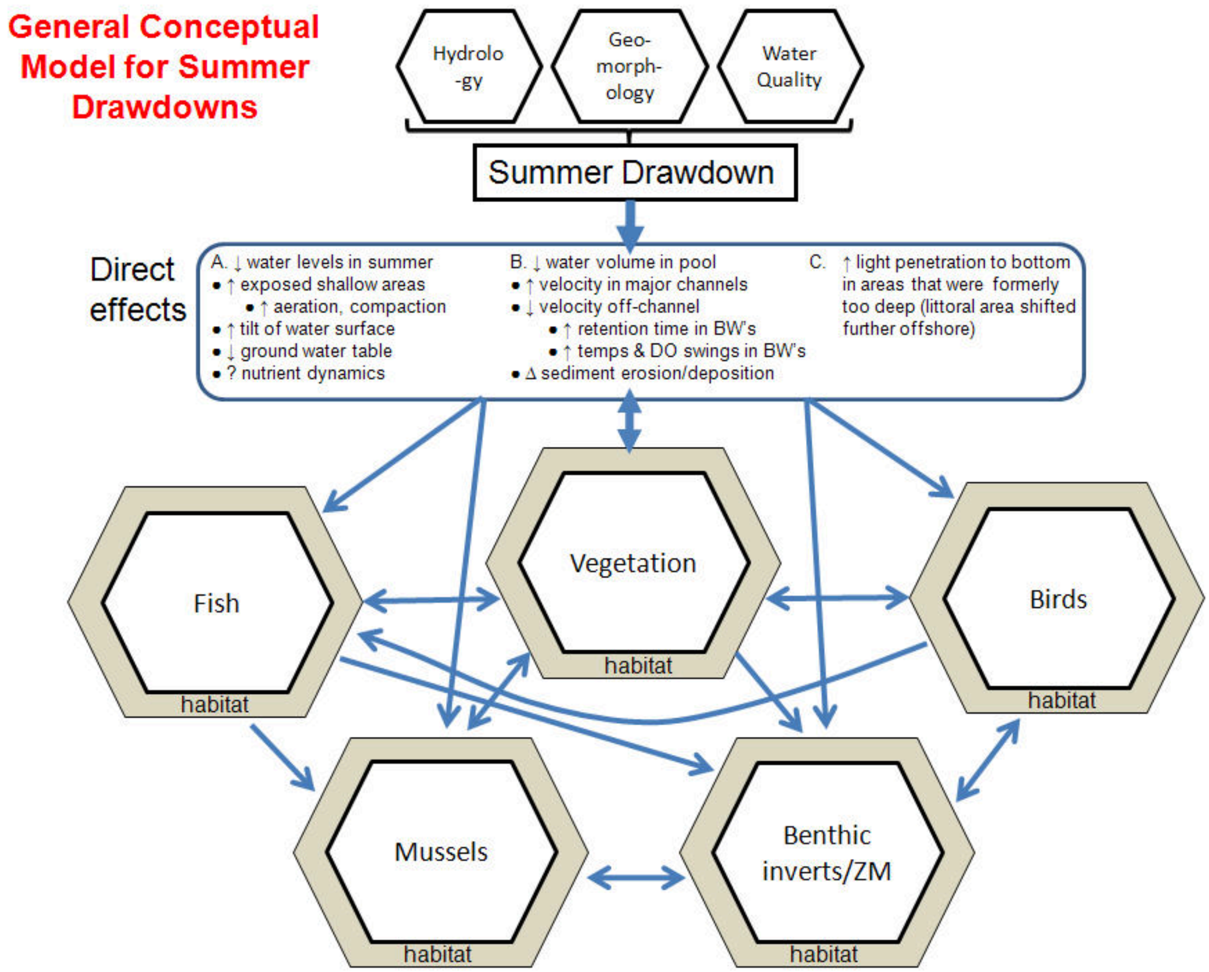


Figure 5. General conceptual model for the direct effects of reducing water levels during summer (drawdowns) on the Upper Mississippi River System. Each of the five ecological components is affected directly by the drawdown, but also by interactions among components. The shaded areas surrounding each component hexagon indicate that many effects are expressed through, or as, changes in habitats.

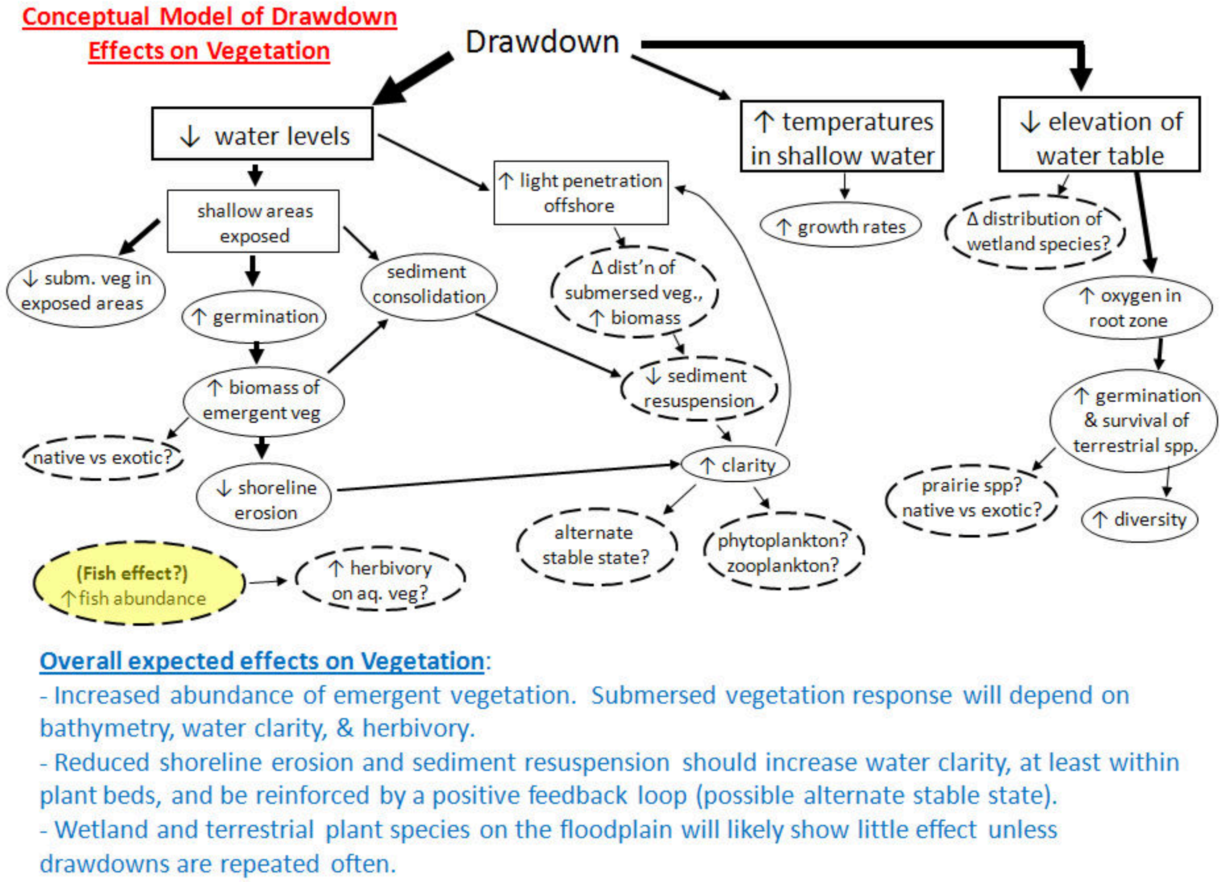
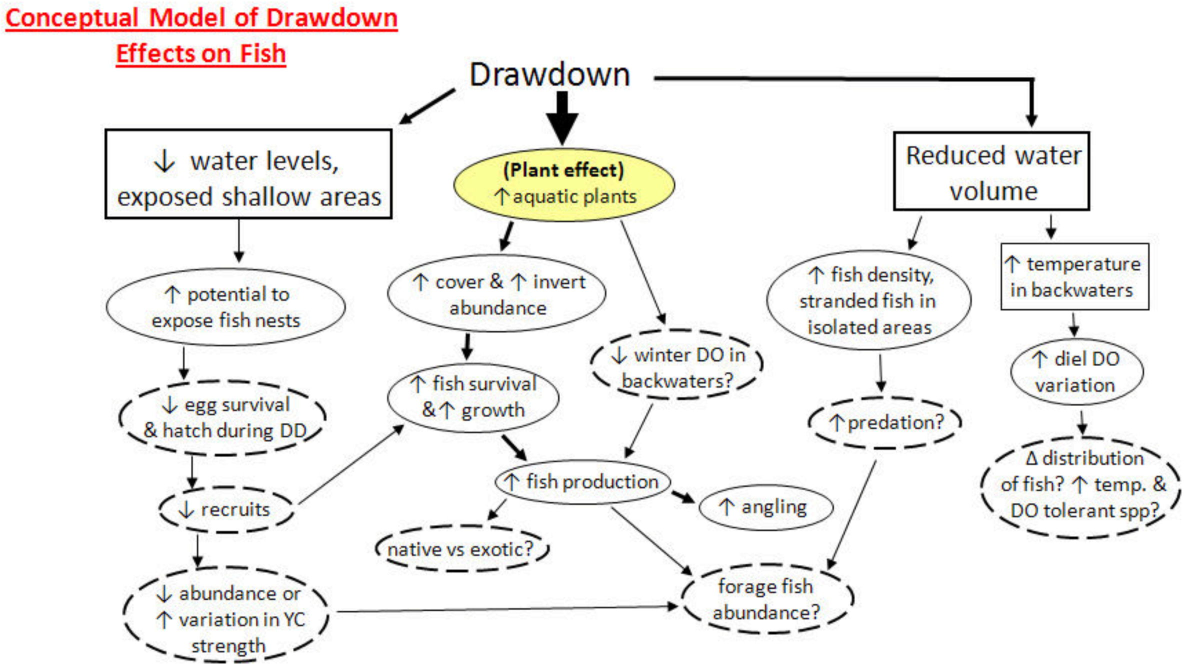


Figure 6. Conceptual model for the effects of summer drawdowns on vegetation. The boxes indicate direct physical effects. Ovals indicate ecological effects, with yellow ovals indicating effects derived from an ecological change in another component. The sizes of the arrows represent the expected strength of the interaction. Dashed lines for an oval indicate an uncertain effect.



Overall expected effects on Fish:

- Increased plant abundance should increase fish recruitment and abundance and thus, fishing success.
- Exposing shorelines may increase mortality of eggs in nests and reduce hatching success, but this may be offset by a compensatory increase in survival & growth of juveniles.

Figure 7. Conceptual model for the effects of summer drawdowns on fish. The boxes indicate direct physical effects. Ovals indicate ecological effects, with yellow ovals indicating effects derived from an ecological change in another component. The sizes of the arrows represent the expected strength of the interaction. Dashed lines for an oval indicate an uncertain effect.

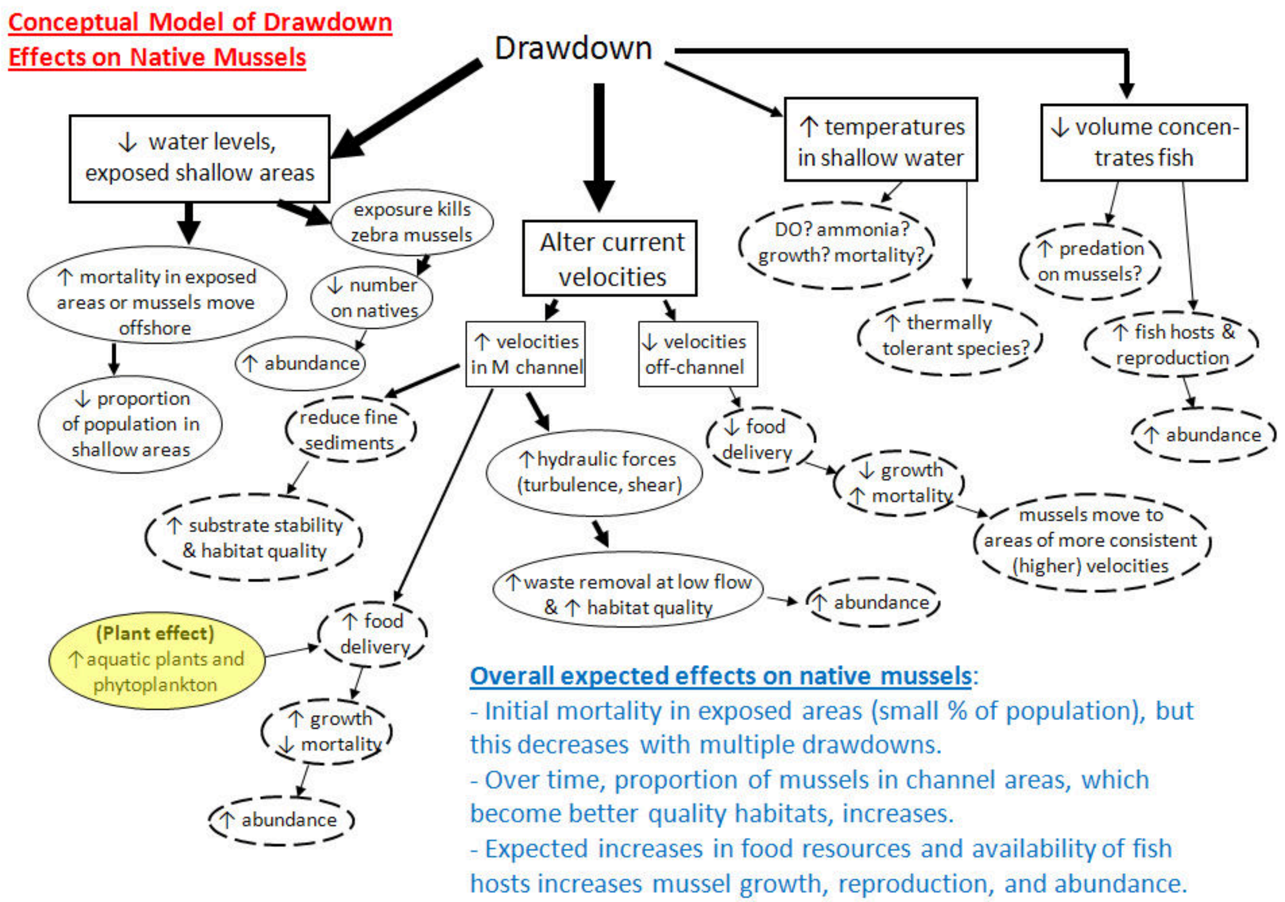
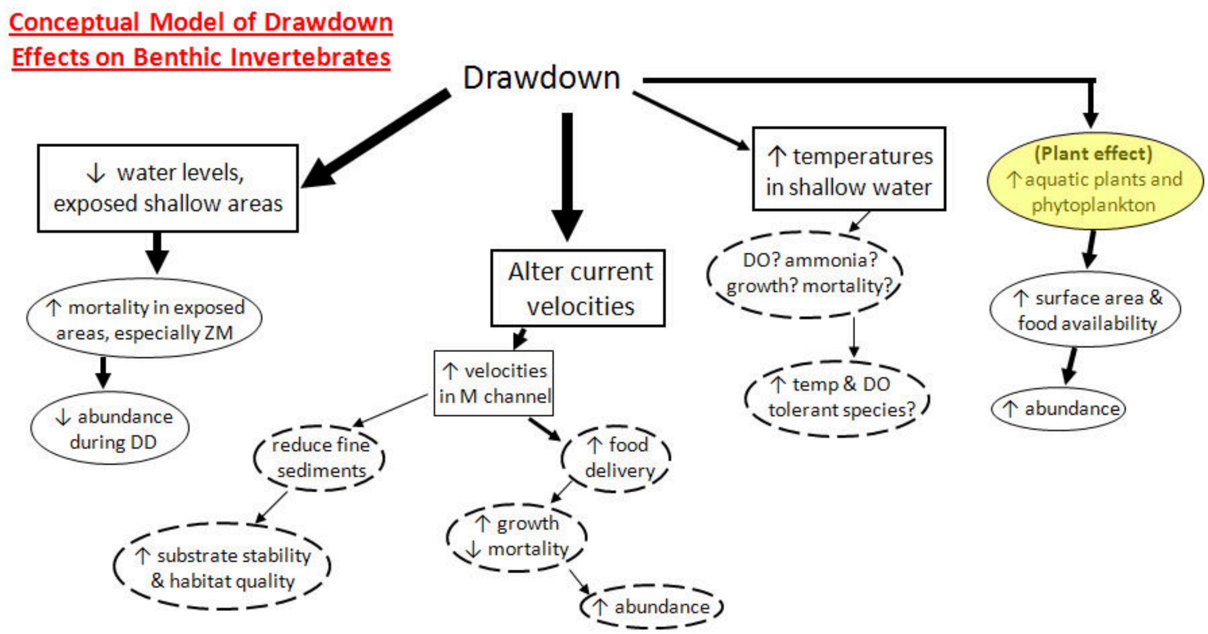


Figure 8. Conceptual model for the effects of summer drawdowns on mussels. The boxes indicate direct physical effects. Ovals indicate ecological effects, with yellow ovals indicating effects derived from an ecological change in another component. The sizes of the arrows represent the expected strength of the interaction. Dashed lines for an oval indicate an uncertain effect.



Overall expected effects on Benthic Invertebrates:

- Initial mortality in exposed areas, especially zebra mussels.
- Increase in aquatic plants increases surface area and food resources for invertebrates and increases their production.
- Increased food delivery in main channel increases growth & abundance of invertebrates.

Figure 9. Conceptual model for the effects of summer drawdowns on benthic invertebrates. The boxes indicate direct physical effects. Ovals indicate ecological effects, with yellow ovals indicating effects derived from an ecological change in another component. The sizes of the arrows represent the expected strength of the interaction. Dashed lines for an oval indicate an uncertain effect.

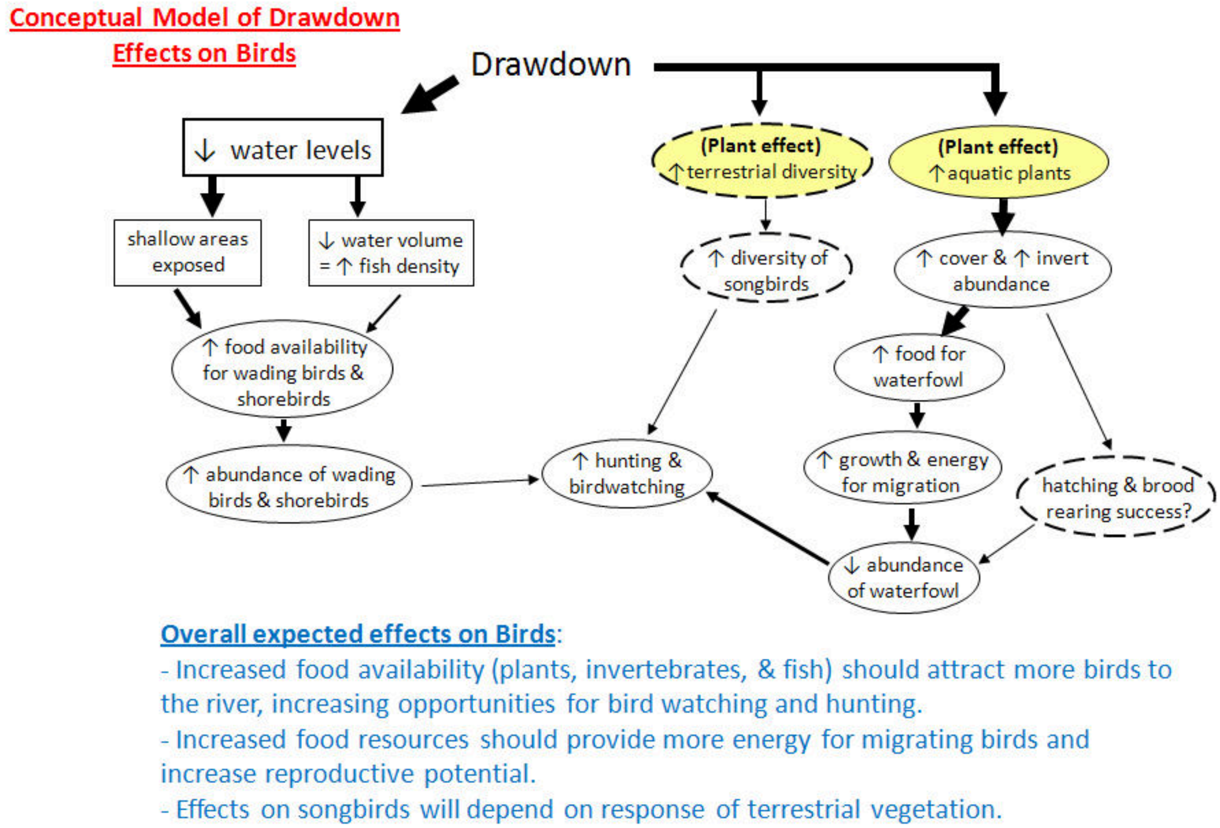


Figure 10. Conceptual model for the effects of summer drawdowns on birds. The boxes indicate direct physical effects. Ovals indicate ecological effects, with yellow ovals indicating effects derived from an ecological change in another component. The sizes of the arrows represent the expected strength of the interaction. Dashed lines for an oval indicate an uncertain effect.

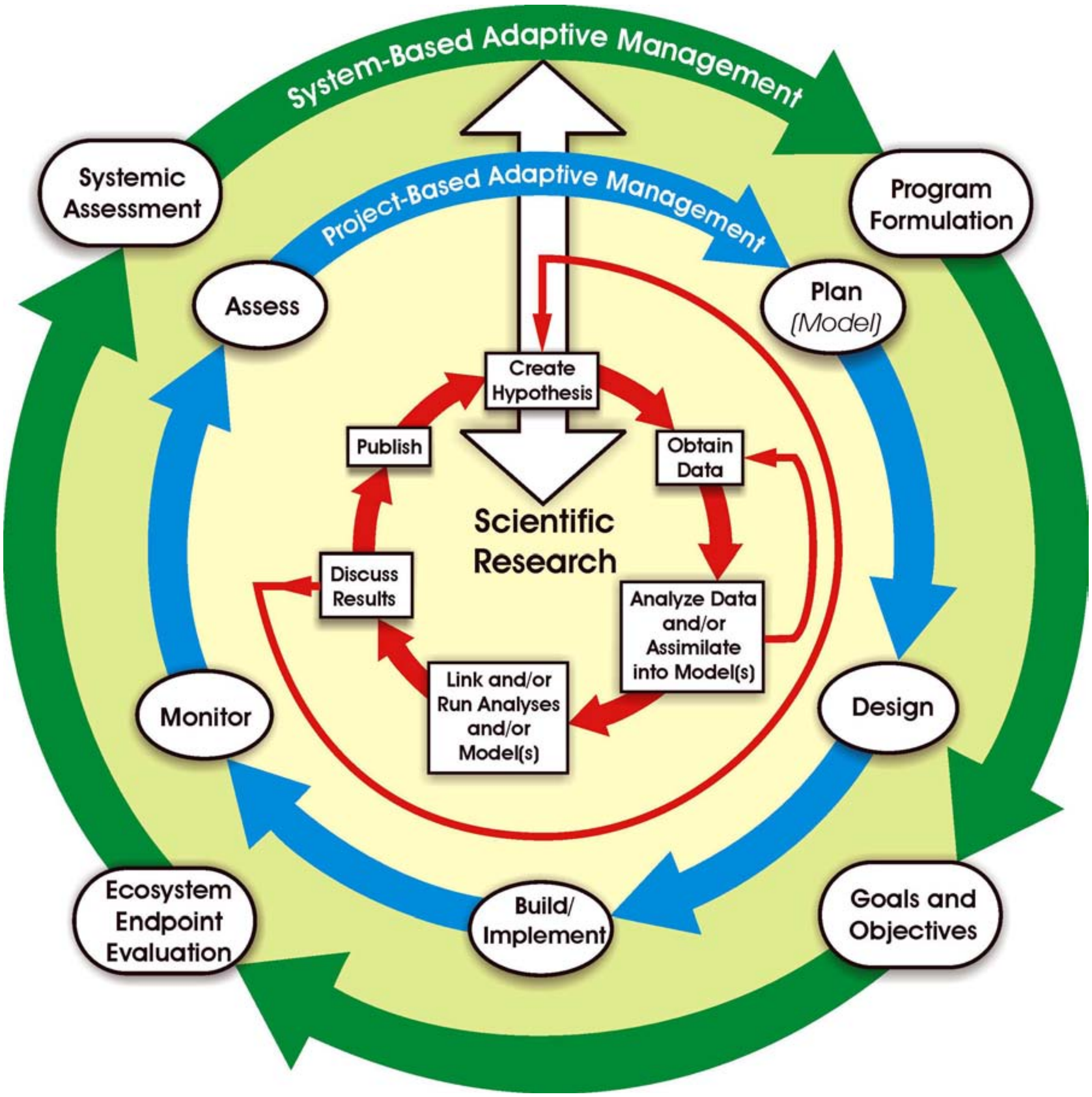


Figure 11. Three nested levels of adaptive management as applied to the Upper Mississippi River System, and their interaction. Levels include learning (inner), project-based (middle), and system-based (outer).

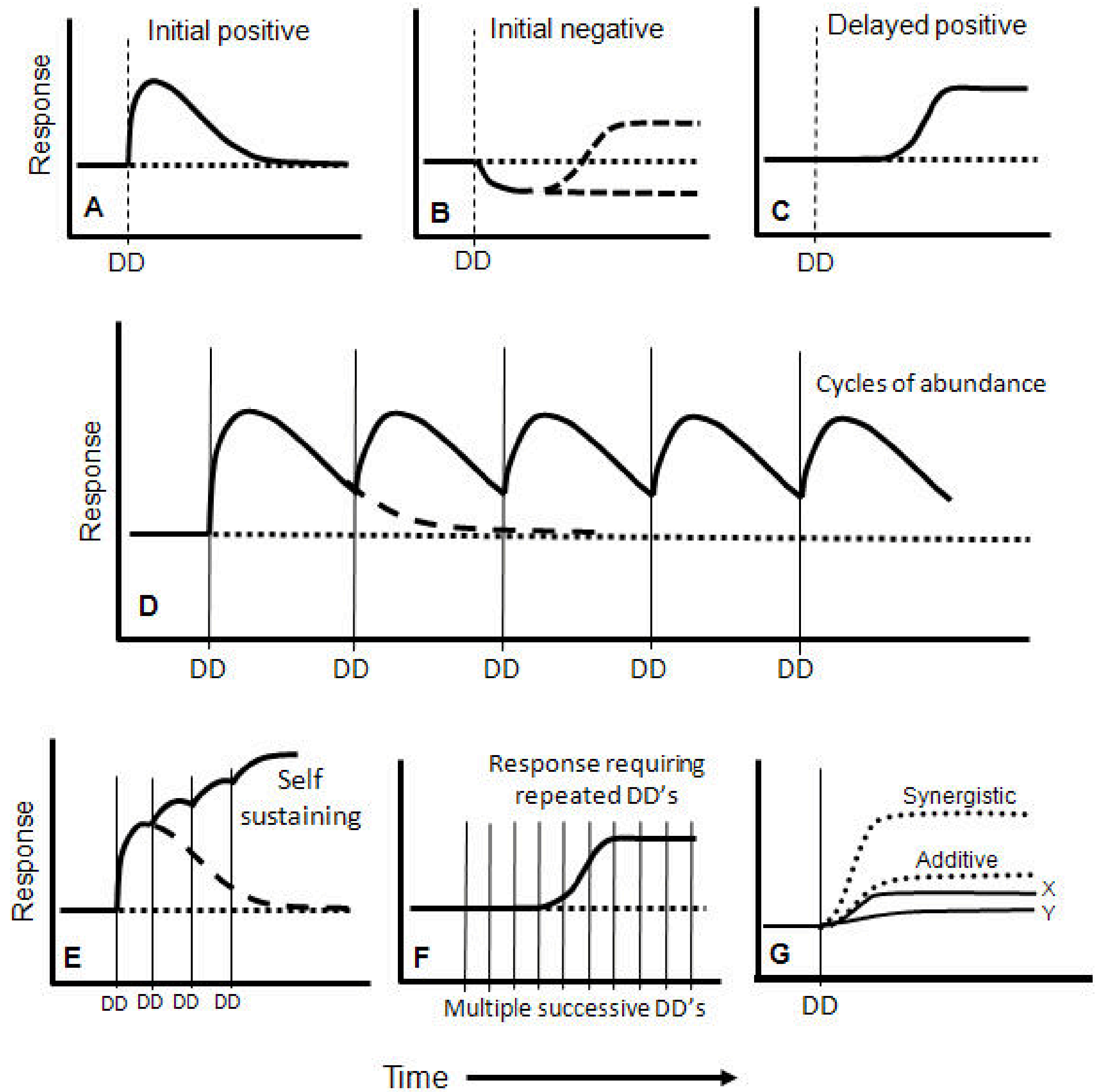


Figure 12. Potential response trajectories for drawdown (DD) effects. "DD" indicates when a drawdown is implemented. (A) Initial response followed by decay, (B) initial decrease followed by continued low levels or an increase, (C) delayed increase from a single DD, (D) multiple cycles of increase and decay, (E) drawdowns repeated often enough to create a self-sustaining response, (F) a response that occurs only after successive repeated drawdowns, and (G) responses of two components expressed individually, as an additive response, and as a synergistic response.

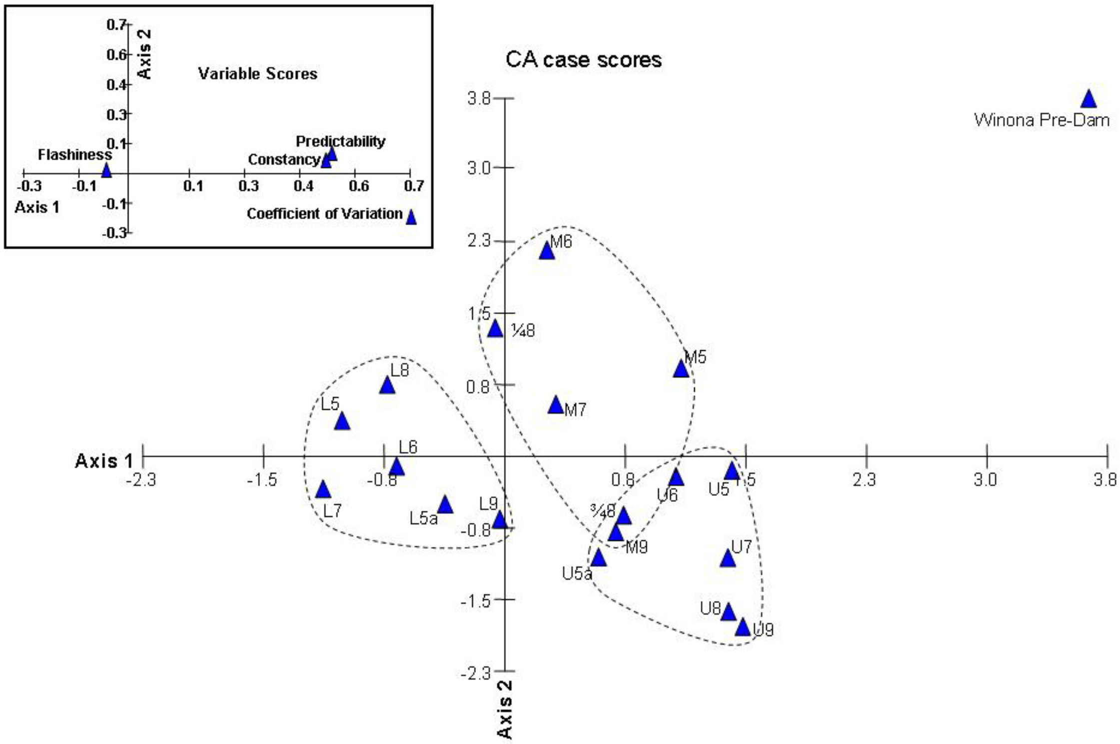


Figure 13. Inherent spatial scaling of hydrologic conditions within geomorphic reach 3 (pools 5-9) of the UMRS based on correspondence analysis of stage data using the following four variables developed from Indictors of Hydrologic Alteration (The Nature Conservancy 2007): coefficient of annual variation, predictability, constancy, and flashiness for gage scores and variable scores (inset). Note that similar relative zones within pool are more alike than pools. That is, the lower reaches of each pool are more hydrologically similar to each other than individual pools are to each other. The variable score plot shows that axis one (96.3%) defines a gradient from low flashiness to predictable whereas axis two (3.5%) reflects constancy and coefficient of variation. Lower pools have high flashiness within a narrow range of variation whereas upper pools tend to show more predictable variation (i.e., seasonal flooding) with middle pools being intermediate in hydrologic pattern, but trending toward greater constancy. Legend: L=lower pool, M=mid pool, and U=upper pool gages.