Recommendations Regarding Water Level Management to Achieve Ecological Goals in the Upper Mississippi River System

A final report to the Upper Mississippi River Basin Association

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UMRBA
Upper Mississippi River Basin Association

Acknowledgments

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The final published report will be publicly available and accessible on the Upper Mississippi River Basin Association's website (www.umrba.org). All original data presented in the tables and unedited workshop notes can be obtained by contacting the corresponding author, Lauren Salvato (lsalvato@umrba.org).

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Definitions

The definitions listed below are provided to add clarity to nuances within the discussions documented, and recommendations put forth, in this report.

What is not well defined are the meanings associated with the terms "water level management," "drawdowns," and "environmental pool management." In part, previous uses of those terms have caused confusion about their meaning as it relates to Upper Mississippi River management. Participants involved in the structured decision making workshops decided not to flesh out the meanings of the terms. Generally, water level management and drawdown describe the deliberate action of lowering the water surface elevation of wetlands, lakes, or river pools for the purpose of stimulating aquatic seed germination, improving aquatic plant and animal diversity, consolidating wetland soils, among other effects described in the "Ecological Effects" section below. Both of these terms are used throughout this report with this intent. Environmental Pool Management (EPM) is a term created by the U.S. Army Corps of Engineers for managing the navigation pools to generate ecosystem benefit within a pool's operating band or routine operation limits. To date, EPM has been implemented in St. Louis District in Mississippi River pools 24, 25, 26 and the Kaskaskia pool on the Kaskaskia River. The flexibility to perform EPM varies within current USACE pool operating manuals.

Ecosystem status	The current chemical and biological conditions of the river, as defined by measured ecological indicators (De Jager et al. 2018) that are important to riverine health, partnership values, and restoration priorities (McCain et al. 2018).
Ecosystem function	The activities of life (including microbes, plants, and animals) that facilitate the exchange of energy and nutrients that sustain life and promote native biodiversity. Activities can include water purification, decomposition of organic matter, and biomass production.
Ecosystem resilience	The ability of an ecosystem to recover after disturbances in the local environment. Characteristics of a resilient ecosystem include, diversity, redundancy, decentralization, self-renewal, self-repair, and the ability to maintain function despite a disturbance (Bouska et al. 2018). Bouska et al. (2019) identified ten measurable ecological indicators for the Mississippi River that 1) highlight important ecosystem structure and function, and 2) test resilience principles that underlie the capacity of the system to cope with environmental changes.
Operationalization of water level management	Regular, planned use of WLM over the next 25–50 years within pools of the UMRS under primary jurisdiction of U.S. Army Corps of Engineers (USACE) Districts, including St. Paul (MVP), Rock Island (MVR), and St. Louis (MVS).
Condition of aquatic vegetation	Workshop participants created a threshold definition for "good" and "poor" aquatic vegetation conditions in a pool. Good condition indicates native aquatic vegetation covering at least 25 – 50% of the photic zone (i.e., less than 1.5 meter water depth). Poor condition indicates native aquatic vegetation covering less than 25% of the photic zone. Workshop participants recommend refining this definition after review of existing scientific literature and further discussion with current partners. Additional ecological state variables that could define good ecological condition are referenced in Appendix 2.

Executive Summary

The Water Level Management Regional Coordinating Committee tasked an *ad hoc* group to employ structured decision making (SDM) practices to reach partnership agreement around a set of basic recommendations as to when, where, and why WLM should be used as an ecosystem restoration tool in the UMRS. Between April 2021 and August 2021, the Upper Mississippi River Basin Association (UMRBA; www.umrba.org) hosted a series of six virtual meetings for the *ad hoc* group to evaluate the issues, explore agency perspectives, and develop shared recommendations for WLM implementation. This report describes the process and outcomes of the SDM exercise.

The *ad hoc* group reached a unified recommendation that the three USACE Districts should each implement water level management (i.e., actively manage for lower water levels with depths and duration to be determined) in one pool considered to be in "good" ecological condition and one pool considered to be in "poor" condition and assess the impacts of those actions by using a collaboratively developed adaptive monitoring framework lead by UMRBA and associated scientists.

The *ad hoc* group agreed upon and sequenced a suite of seven recommendations that would allow USACE Districts to implement WLM to achieve ecological objectives. Ultimately, the recommendations will be submitted to the UMRBA Board and USACE Division and District leadership. These recommendations are not binding on federal and state governments.

The *ad hoc* group recommends that USACE Districts allow operationalizing WLM when needed to achieve ecological objectives. This includes incorporating the ability to implement water level management in pool operating manuals and other long term planning documents (i.e., 25 years to 50 years) so that it can be used when managers decide it is an appropriate tool to meet ecological objectives. The *ad hoc* group agreed that WLM should be applied under certain ecological conditions and with clear expectations of desired outcomes that will be developed through continued partnership and study.

To ensure proper implementation of WLM, the *ad hoc* group recommends the use of a new decision-making exercise for characterizing pool condition and for developing an adaptive management framework to promote learning and improve decision making. It is essential that the adaptive management and monitoring framework, including analyses of expected value of perfect information, is established and employed prior to WLM implementation.

In response to uncertainty expressed during the SDM sessions, the *ad hoc* group evaluated several ecological monitoring measures that could help assess the ecological benefits and risks of WLM related to maintaining pools in "good" ecological condition. However, establishing firm targets and acceptable levels for the ecological measures were beyond the scope of this SDM workshop.

The next steps for UMRBA and the District-based WLM teams include establishing ecological goals for WLM, developing alternative system models, identifying specific and quantifiable targets and monitoring metrics, conducting expected value of perfect information analyses to aid in selecting metrics, and developing monitoring plans. SDM might be utilized to reach collective agreement among river management agencies for each of those next steps.

Recommendations

The following recommendations from the *ad hoc* group are intended for the primary decision makers, who are noted in parentheses for each recommendation.

1) Incorporate the option for using WLM to improve ecological function and integrity as a routine function in long term (about 25-50 years) planning documents and USACE pool operating manuals. (USACE)

2) Establish a "WLM team" in the USACE Rock Island District, analogous to the St. Paul District's Water Level Management Task Force and the St. Louis District's Environmental Pool Management Team, to improve coordination of WLM planning, implementation, and analysis across Districts. All three District-based teams should interact to share information and use the adaptive management framework across the system. The WLM teams could also develop an initial list of prioritized pools for implementing WLM. (USACE, WLM teams)

3) Continue with decision analysis prior to operationalization of WLM. The WLM teams would benefit from facilitation by a trained decision analyst to further establish stated ecological goals for WLM, define specific and quantifiable targets and within-pool ecological conditions necessary to set WLM in motion, address definitions, system models, concerns, risk tolerance, and expected value of information for candidate measures within an adaptive management and monitoring framework. (UMRBA, the a*d hoc* group, WLM teams)

4) Develop and implement an adaptive management and monitoring framework for ongoing learning and achieving stated ecological objectives with a trained decision analyst. Next steps include but are not limited to: (UMRBA, the *ad hoc* group, WLM teams, Upper Midwest Environmental Science Center (UMESC))
    a) Develop system models and specific, quantifiable performance measures to assess pool conditions that help determine when and where to conduct WLM and allow for assessment of the effects of WLM implementation when it occurs
    b) Conduct an expected value of information analysis on each measure prior to implementation
    c) Develop effectiveness monitoring in an adaptive management and monitoring framework with analyses led by UMESC

5) Characterize the ecological condition of each pool (poor versus good) as an aid in selecting and prioritizing pools within Districts for WLM. (UMRBA, the *ad hoc* group, WLM teams)

6) Following additional decision analysis and development of evaluation protocols as recommended in 3 and 4, conduct WLM in one pool in "good" condition and one pool each in "poor" condition in each District following the agreed upon process. (USACE, WLM teams)

7) After recommendations 1–6 are achieved, use the lessons learned to determine whether WLM achieved the ecological objectives or future desired conditions, and create an operation plan and schedule for WLM implementation. (USACE, WLM teams)

The Structured Decision-Making Process

Structured decision-making (SDM) is a deliberate, collaborative, organized, and transparent process for breaking down a challenging natural resource problem, stating the problem as a decision, and then focusing on specific objectives for that decision (Gregory et al. 2012; Hammond et al. 2002). Once the objectives are clarified, a range of alternative actions are generated and evaluated by comparing the predicted outcomes or consequences of each action and assessing tradeoffs among the alternatives. The process is deliberate in that alternatives are carefully considered. The "best" alternative will meet most, if not all, of the stated objectives. A facilitator led the a*d hoc* group through iterations of the "SDM PrOACT cycle," which is as follows: defining the problem (i.e., decision framing), stating the objective(s), developing alternatives, predicting the resulting outcomes (or consequences) of each alternative, and considering the trade-offs among the alternatives (Hammond et al. 2002; Figure 1). The *ad hoc* group recommendations to decision makers and their response will fulfill the "Decide and Take Action" as the final step in the PrOACT cycle.

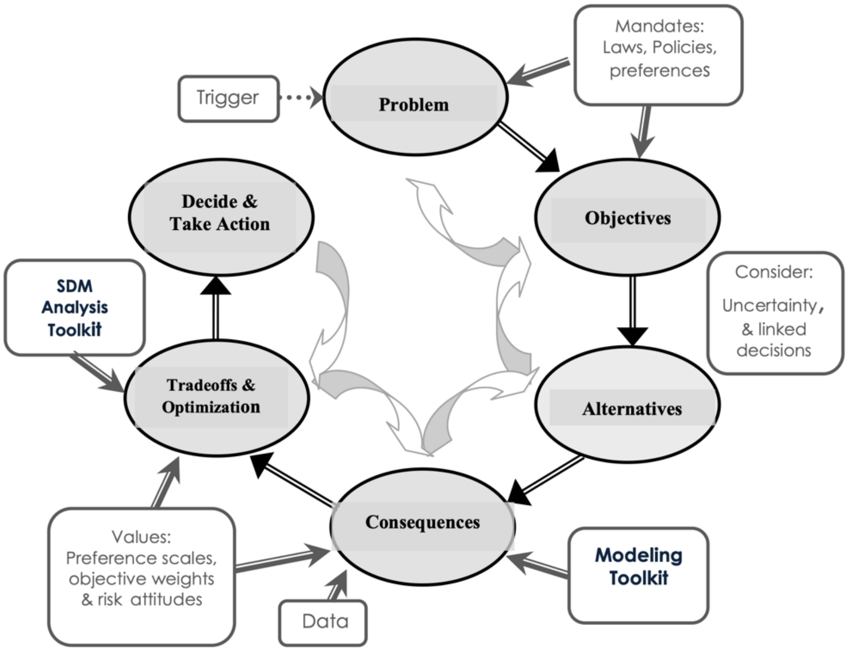


Figure 1. The PrOACT cycle. The *ad hoc* group completed the PrOACT cycle during the workshop and then provided recommendations to decision makers for consideration to "Decide and Take Action" as the final step. Design by Jean Cochran for the Department of the Interior National Conservation Training Center, Shepherdstown, West Virginia. Used with permission of the National Conservation Training Center.

Decision Framing for Water Level Management

Historical and Political Context

There have been ongoing deliberations among restoration practitioners (particularly in MVP and MVR) regarding the anticipated benefits, the implementation challenges, ecological risks, and financial costs of drawdowns as well as public perspectives. This section of the report provides a historical and political context of pool-scale WLM implementation to-date.

The pools of the UMRS were created in the 1920's and 1930's by the construction of a series of locks and dams to improve navigability of the river. The UMRS consisted of a main channel and braided side channel habitats prior to dam construction. Total aquatic area in the main stem of the Upper Mississippi River increased substantially after dam construction inundated large portions of the floodplain to form pools upriver of the dams. The newly regulated river had abundant aquatic vegetation growth in response to the new aquatic areas created by the dams (Fremling 2005). However, aquatic vegetation declined after years of relatively stable water levels and chronic high turbidity. On the Illinois River, most aquatic vegetation loss occurred between the 1920s and 1950s, mostly attributed to urban waste discharge, increased water level fluctuations, and high suspended sediment concentrations (Mills et al. 1966, Sparks et al. 1990). In the main stem of the Upper Mississippi River, aquatic vegetation severely declined in the late 1980s after years of relatively stable water levels and chronic high turbidity. Fischer and Claflin (1995) hypothesized that the loss of aquatic vegetation stemmed from a combination of severe drought, high nutrient inputs, and increased wind fetch due to island erosion that impaired water quality. Since the late 1980s, aquatic vegetation has increased in some areas of the UMRS, potentially stimulated by low discharge, decreased water velocity, and greater water clarity (Burdis et al. 2020) as well as construction of habitat restoration and enhancement projects (HREPs) by the Upper Mississippi River Restoration (UMRR) program and several WLM projects conducted in select pools. More history of aquatic vegetation in the UMRS can be found in Larson et al. (2022).

The St. Louis District (MVS) regularly implements pool wide WLM in Pools 24–-26 within approved operating levels as described within the existing operating manuals. Whereas there has been tremendous success in emergent vegetation response, restoration practitioners within MVS believe that outcomes would be improved if drawdowns were implemented beyond the operating band – i.e., greater water depth of drawdown.

Several WLM projects on the Illinois River during the 1990s and 2000s were evaluated with biomonitoring of native and non-native fishes, wetland plants, waterbirds, dissolved oxygen concentration, sediment consolidation, and water quality. Those results are summarized in Theiling et al. (2015).

The MVP and MVR Districts have not routinely applied WLM for various technical reasons (reviewed in Kenow et al. 2016), but a few experimental applications of WLM have demonstrated positive ecological response to drawdown. In these two districts, pools are generally operated within a much narrower operating band, and WLM outside of the approved operating band requires either an approved deviation request for dam operation or a provision in the pool water control plans that explicitly allows for WLM. Additionally, WLM can be employed under the project-specific authorities of UMRR or the Navigation and Ecosystem Sustainability Program. In the 1990s, Pool 5 underwent exploratory, small-scale drawdowns in select backwaters. These drawdowns resulted in increased coverage of emergent floodplain vegetation in the backwaters (Theiling et al. 2021) and about 15% reductions in submersed plant cover (Kenow et al. 2016). This effort was led by the MVP District-based Water Level Management Task Force (WLMTF).

MVP used the knowledge gained from the small-scale drawdowns to implement pool-scale drawdowns in Pool 8 (2001-2002), Pool 5 (2005), and Pool 6 (2010). Studies of these pool-wide drawdowns detected positive responses by several plant communities as well as an increase in the habitat for fish spawning and migrating water birds (Kenow and Lyon 2009, Theiling et al. 2021). Custer et al. (2007) reported that, following a 2001 drawdown in Pool 8, concentrations of contaminants like mercury and organochlorine compounds in tree swallows were stable and did not increase as hypothesized. Kenow and Lyon (2009) monitored the seedbank community and plant species composition after the Pool 8 drawdown in 2001. The authors observed the germination of 47 plant species and found a correlation between the species composition of the germinated seedlings and the plant community species composition in Pool 8 after a 2001 drawdown. MVP has not implemented WLM since 2010 (Theiling et al. 2021). Currently, MVR is evaluating plans for multiple drawdowns over a 50-year project life as part of an UMRR HREP in Pool 13.

In part, risk assessments and research findings have halted WLM plans in the UMRS. For example, MVR considered a drawdown in Pool 18 in 2007– 2008. However, WLM was not ultimately implemented due to the potential risk of mussel mortality after surveys conducted prior to drawdown found state-listed species were highly abundant (Zigler et al. 2012).

Theiling and Nestler (2010) analyzed river stage hydrology in all geomorphic reaches of the UMRS and concluded that water levels can be managed throughout the system to maintain navigation while providing ecological benefits to species, habitats, and ecosystem processes. As examples, increased abundance of emergent vegetation was documented during and after WLM efforts in all three UMRS Districts (Woltemade 1997, Sparks et al. 1998, Flinn et al. 2005, Nissen 2014, Kenow et al. 2016, Coulter et al. 2019). These scientific evaluations coupled with WLM actions have spurred ongoing interest in operationalizing WLM throughout the system.

Given that WLM has not been implemented in 12 years due to the aforementioned risks and barriers, the WLMTF approached UMRBA about addressing the risks and barriers at the basin level. In 2018, UMRBA (www.umrba.org) formed the WLM Regional Coordinating Committee (RCC) with the mission "to promote systemic, routine, and coordinated water level variation, address policy and funding needs, advance interdisciplinary monitoring and research, and inform and engage the public" (Appendix 1). In 2018, the WLM RCC set a suite of primary roles to advance its vision and mission, as follows:

- Provide a forum for implementing partners to discuss policy and technical issues related to WLM
- Identify and communicate member agencies' and organizations' perspectives on WLM implementation issues to USACE and other decision makers
- Advise relevant agency leadership and management regarding the implications of policy, programmatic, and budget decisions affecting WLM implementation
- Identify WLM priorities (e.g., communications, economic analyses, and research) and seek resources
- Promote shared learning of WLM implementation within a broader spatial and temporal scope

After decades of deliberation around the ecological effects of drawdowns, the WLM RCC agreed to work through a SDM process with a neutral facilitator to identify ecological objectives and measurable criteria, future desired conditions, and some basic recommendations for operationalizing WLM (the basis of this report).

Ad Hoc Group Roles

The authority to control water levels within the UMRS through manipulation of the navigation dams is vested with the Commanding General, Mississippi Valley Division through operational command exercised by the three UMRS District Commanders (MVP, MVR, MVS). Input from stakeholders and resource agencies are important considerations when USACE evaluates requests for deviations in WLM. Senior leadership from USACE or the other resource agencies did not attend these workshops. Instead, members of the *ad hoc* group served as informal, proxy decision makers for their organization or agency to facilitate the SDM process. In this capacity, the *ad hoc* group developed a unified compilation of recommendations in this report to provide to leaders of USACE and other agencies as well as key sets of stakeholders. The workshop participants chose not to address how drawdowns may be authorized but instead focused on the ecological needs and outcomes of WLM.

Geographic Area of Consideration

The *ad hoc* group agreed that hydrogeomorphology of the pool (see De Jager et al. 2018, Carhart et al. 2021) and dam operating configuration would serve as the basis for selecting candidate pools for WLM. Per those factors, the *ad hoc* group identified the following pools as possible candidates for WLM:

- MVP: Upper Mississippi River Pools 2 – 10
- MVR: UMR Pools 11 – 22 and sections of Illinois Waterway like Marseilles, Starved Rock, Peoria, and La Grange Pools
- MVS: UMR Pools 24 – 26

Time Frame

The operationalization of WLM should be over the next 25 to 50 years.

Problem Statement

The *ad hoc* group defined the problem to analyze as follows:

> *Currently there are no clear ecological objectives for selecting pools for WLM, and no agreed upon process for selecting and prioritizing pools for drawdowns. The ad hoc group wishes to provide a unified recommendation to USACE MVD and District leadership and others regarding why, where, when, and how to operationalize water level management in the UMRS. The primary goals of WLM are ecosystem restoration and enhancement within constraints of the costs and requirements of commercial navigation, recreational user access, and river dependent businesses.*

Challenges and Costs Associated with WLM

Logistical constraints, cost, and uncertainties regarding the outcomes in riverine habitats makes systemic, operationalization of WLM challenging (Wlosinski and Hill 1995, Kenow et al. 2016). For example, unexpected weather such as rain, ice, wind, and rapidly fluctuating discharges create difficulties in meeting drawdown targets (Wlosinski and Hill 1995). Further, Kenow et al. (2016) explained the difficulties with the process and policy of implementing WLM. The USACE has Congressional authorization to maintain a 9-foot navigation channel on the UMRS and does so through managing water levels with Locks and Dams and dredging. Conducting WLM outside of authorized bounds requires not only an approved deviation but may also require additional dredging to ensure the required channel width and depth are maintained during drawdown. Additionally, marinas, boat launches, or other river users could be temporarily but adversely affected by the drawdown.

Incorporating WLM as a routine function in long term (>25 year) operating manuals and associated plans eases the resource requirements associated with one-time planning needs. However, operationalization of WLM requires agreement among the resource agencies with decision-making authorities as to which pools to pursue WLM and how often. The *ad hoc* group provided some initial ideas and recommendations in the “Operationalizing WLM” section below to begin addressing the “Problem Statement.”

Potential mussel mortality, financial costs, and stakeholder experiences are concerns when considering drawing down any pool (e.g., Nissen 2014, Newton et al. 2014, Kenow et al. 2016). The *ad hoc* group expressed a key uncertainty of whether pools in good condition will be negatively affected by repeated drawdowns. Negative effects of WLM include the potential mortality of mussels (Newton et al. 2014) and fish (Larson et al. 2020), loss of submersed aquatic vegetation due to dewatering (Kenow et al. 2016), temporary loss of public access to some pool areas, marinas, and boat ramps, and the additional dredging costs to maintain navigation channels.

Regardless of frequency of occurrence, drawdowns for any given pool require years of advanced planning and successful implementation depends on seasonal discharge (Kenow et al. 2016). Implementing WLM is subject to environmental conditions before and during the drawdown. Drawdowns often target a 90-day period of reduced water depth. Unexpected or extreme precipitation events can result in either short-term (<7 days) or long-term (>7 days) re-wetting events. Three or fewer short-term rewetting events have been considered acceptable during past drawdowns, but complete and prolonged re-wetting (> 2 weeks) can essentially terminate a drawdown. For example, a drawdown in Pool 6 was considered a failed attempt when it ended after less than 30 days (Nissen 2014).

Ecological Effects

Managers use WLM as a tool to increase emergent vegetation abundance and diversity on the UMRS (Johnson et al. 2010). Drawdowns have been implemented in Pools 24–26 annually for the past 20 years and have demonstrated enhanced emergent vegetation among other positive ecological effects (Woltemade 1997, Sparks et al. 1998, Theiling and Nester 2010, Kenow et al. 2016, Theiling et al. 2021). For example, WLM in Pool 25 has been associated with increased emergent vegetation, associated organic matter, and invertebrates (Flinn et al. 2005). Additionally, increased emergent vegetation associated with WLM was heavily used by young-of-year fishes in Pool 25 (Coulter et al. 2019). Experimental drawdowns in Pools 24–26 showed that emergent vegetation increased ten-fold in one pool when compared to a nearby pool that was not drawn down, and negative impacts to the fish community were not observed (Wlosinski et al. 2000).

Only a few experimental drawdowns have occurred in MVP over the same time span because WLM in this District requires deviations from the operating band, which is complex and costly (Kenow et al. 2016, Theiling et al. 2021). WLM was experimentally applied in the mid-2000s to Pools 5, 6, and 8 to increase emergent vegetation. The emergent plant seedbank in Pool 8 was diverse, widespread throughout the pool, and had highest seedling densities in moist soil areas (Kenow and Lyon 2009, Kenow et al. 2018). Similar to Pool 8, the seedbanks in Pool 18 are diverse but less densely populated with seeds, yet aquatic plant communities are expected to respond positively to drawdowns because Pool 18 seeds are viable (Schorg and Romano 2018). Following three localized backwater drawdowns in MVP, reductions in submersed aquatic vegetation ranged from 0–15%, attributed to either dewatering during drawdown or the late season timing of post drawdown sampling occurring after plants senesced (Kenow et al. 2016). For these drawdowns, it was not clear whether submersed plants continued to decline or rebounded several years after the drawdown because plants were not monitored. However, following several years of low water discharge and turbidity (2006, 2007, and 2009) in Pool 4 there was a significant increase in submersed aquatic vegetation (Burdis et al. 2020). Further, submersed plant abundance and diversity substantially increased the spring following drawdowns in other regional systems, and those plants attracted migrating waterfowl and water birds compared to nearby lakes without drawdown (Larson et al. 2020).

Partner discussions and discussions within the SDM workshop suggested that repeated drawdowns may be needed to maintain aquatic vegetation and potentially other ecosystem functions. In nearby lakes with dynamic water levels, high turbidity, and aquatic plant communities, there is evidence that repeated drawdowns are needed to maintain and increase aquatic plant abundance and diversity (Hanson et al. 2017, Larson et al. 2020). In several UMRS pools, seed banks are abundant and diverse within proposed drawdown areas of Pools 7 and 8, indicating the potential for increased vegetation in response to periodic WLM (McFarland and Rogers 1998, Kenow and Lyon 2009).

There is less certainty regarding other ecological benefits that may result from drawdowns. Native fish were more abundant in areas with high variability in water levels, suggesting that WLM may simulate natural drought and give native fish competitive advantage over the non-native fishes (Koel and Sparks 2002). Vegetation growth post-drawdown may reduce shoreline erosion and sediment resuspension (Korschgen 1988, Janecek 1988) and thus reduce turbidity (Madsen et al. 2001). Further, studies in other river systems suggest drawdowns may also improve floodplain tree recruitment due to lowering of the water table during the growing season (Stella et al. 2010) and similar ecological benefits may also apply to the UMRS. More information is needed to understand whether repeated drawdowns affect fish spawning and rearing habitat and water quality, particularly in pools in good ecological condition.

Considerations

Considerations to WLM throughout pools in the UMRS have been previously identified (Lubinski et al. 1991, Landwehr et al. 2004, Kenow et al. 2016) and continue to date. The primary considerations include:

- Maintenance of the 9-foot-deep navigation channel

- Control of the system
    - Examples include type of water control (i.e., dam point, control point, primary-secondary-tertiary) and the probability of successful implementation (drawdown length ≥ 30 – 90 days) due to pool and dam configuration and forecasted or past observed weather conditions
- Compliance with National Environmental Policy Act, Clean Water Act, and any applicable Federal regulations and Executive Orders
- Consideration of environmental justice in all levels of public decision making and engagement of communities potentially affected by WLM

Results

These results were obtained from the SDM process. Over six SDM meetings, the a*d hoc* group articulated the problem statement (provided above). A facilitator guided the *ad hoc* group through a series of steps. The first steps included determining fundamental objectives for WLM, indicators of success, and anticipated negative outcomes. Next, the *ad hoc* group determined the information and policy needs that would be required for operationalizing WLM, including how to characterize the current ecological condition of pools and what environmental conditions indicate a pool might ecologically benefit from WLM.

The outcomes of the steps described above are as follows:

Fundamental and Means Objectives for WLM

1) Maximize ecosystem function within pools and Districts of the UMRS (Figure 1a). Primary bullets indicate the fundamental objective, which describes the desired change in ecological function. The secondary bullets are means objectives, which were a combination of possible metrics and benchmarks for assessing whether the ecological functions were achieved by WLM.

   Increased ecological function is defined as:

   - Increased nutrient uptake and denitrification
     - Reduced water column nitrate (mg/L), which may indicate sediment consolidation or increased denitrification to the atmosphere
     - Increased sediment-nitrogen content (mg/L) from consolidation
     - Increased nutrient uptake by aquatic plants (Cavanaugh et al. 2006, Kreiling et al. 2011)
   - Protected shorelines by increased emergent and submergent plant habitats, reduced bank erosion, and improved forest regeneration
     - Increased number of bank miles protected (meters) by emergent vegetation beds
     - Increased areal extent of aquatic vegetation reducing wave movement
     - Increased density of native aquatic plants
     - Increased forest regeneration rates (e.g., Increased seedling and sapling survival)
   - Increased or maintain diversity of native mussels
     - Measured as mussel density, catch per unit effort, and species diversity within a pool
     - Minimized native mussel mortality within drawdown sites
     - Modeled native mussel bed distribution

- Increased fish spawning and rearing habitat
    - Increased in young-of-the year native fishes (catch/unit effort) – although this cannot currently be directly tied to the increase in aquatic vegetation
    - Considered alternate life stages to directly measure

- Increased food for waterfowl
    - Increased in biomass of tubers (mg/m2) and /or annual seed production (kcal/m2)
    - Increased in abundance and diversity of zooplankton and phytoplankton
    - Increased proportion of land cover of aquatic vegetation (proportional change of vegetation at the pool-scale)
    - Increased zooplankton and phytoplankton abundance as food for fish, water birds and freshwater mussels

- Minimize turbidity at the pool-scale and within new aquatic vegetation beds
    - Increased sediment bulk density
    - Increased water clarity
    - Decreased total suspended solids (mg/L)
    - Increased Secchi depth (m)
    - Increased areal coverage of 1.5 m photic zone (m^2)

2) Maximize ecosystem resilience to short- and long-term physical stressors within pools and across the UMRS (Figure 1b). Resilience is defined as the amount of disturbance that an ecosystem can withstand without changing self-organized processes and structure.

    - Maximize native aquatic vegetation
        - Increased number of species and species diversity
        - Increased diversity of aquatic life forms such as emergent and submergents, shrubs, floodplain forest, and shallow marshes
        - Increased distribution (overall net gain in acres) and diversity of native emergent perennial vegetation within and among pools, especially in the St. Louis District where this is the dominate vegetation type Increased number of emergent plant species/unit effort (Number of species/area)
        - Increased prevalence of emergent vegetation (Proportion of survey sites with emergent vegetation present)
        - Increased distribution and native submergent plants, despite this being harder to quantify and more expensive
        - Increased number of submergent plant species/unit effort (Number of species/area)
        - Increased prevalence of submergent vegetation (Proportion of survey sites with emergent vegetation present)

- Maximize native species diversity and abundance of many native animal species
    - Increased number of species/unit effort
    - Increased multiple diversity indices (e.g., species richness and evenness)
    - Increased diversity and abundance of native fishes
    - Increased diversity of invertebrates and mussels associated with existing aquatic vegetation beds (short-term)
    - Maintained or increased mussel diversity, abundance, and host fish availability (long term)
    - Increased number of species/unit effort
    - Increased species number by functional category associated with existing and new aquatic vegetation beds

3) Minimize effects of WLM on other commercial users, cultural resources, and the public (Figure 1c). These effects can be mitigated by outreach and consulting cultural resource maps prior to drawdown, dredging, and redirecting the public to alternative launches and marinas. Details on the users, types of disruptions, and possible solutions are documented in Appendix 3.

    Minimized effects are defined as:

    - Reduced access to commercial or public use sites (e.g., river boat launches) is minimized
        - Minimized number of sites predicted to be affected during drawdown
        - Maximize number of alternative access points provided
        - Minimized number of marinas that require additional dredging to maintain access
    - Maximize communication and outreach
        - Maximize follow up surveys after WLM to understand impacts to commercial and recreational users
        - Minimized effects on cultural resources (Ex. Pool 9 drawdown discussions were halted because there was concern that people could access and harvest artifacts when exposed). Use shoreline surveys prior to the WLM to document the number, area, value, and type of known cultural resources that would be exposed

4) Maximize learning about system responses during and several years after WLM (Figure 1d) (Lubinski et al. 1991, Johnson et al. 2010, this report). Typically, learning is not included as an objective in SDM. This is because learning will be a component for any WLM alternative/action considered, and therefore does not help differentiate among the proposed alternatives as an objective should do. For this reason, learning was not included in further discussions of objectives or in ranking alternatives. The *ad hoc* group members agreed that learning will play a major role in the future of WLM, and learning is included as a key recommendation.
    Learning was defined as:

    - Increased understanding of ecosystem responses that are directly related to improved future decisions

- Increased factors driving the probability of successful implementation of WLM are explored (see Johnson et al. 2010, which lays out learning needs of that time)
    - Established monitoring before, during, and post-implementation for measures outlined in this document
    - Conducted expected value of perfect information analyses (Runge et al. 2011) for any future, potential research, monitoring, and adaptive management
    - Established a formal adaptive management and monitoring framework for incorporating learning into WLM for components of high uncertainty and high expected value of perfect information (Johnson et al. 2010, Knutson et al. 2010, Williams 2011, Williams 2015, Runge et al. 2020)
    - Conducted targeted research

5) Minimize cost of dredging needed for implementation of WLM (Figure 1e). The net costs for dredging to implement WLM are difficult to estimate because dredging occurs annually for channel maintenance and the increased dredging that may be needed prior to a drawdown may reduce the amount of dredging needed over 1–4 years post-drawdown, off-setting dredging costs (Kenow et al. 2016).

    - Minimized dredging costs
        - Increased synergistic opportunities with other programs
        - Increased beneficial use of dredge material

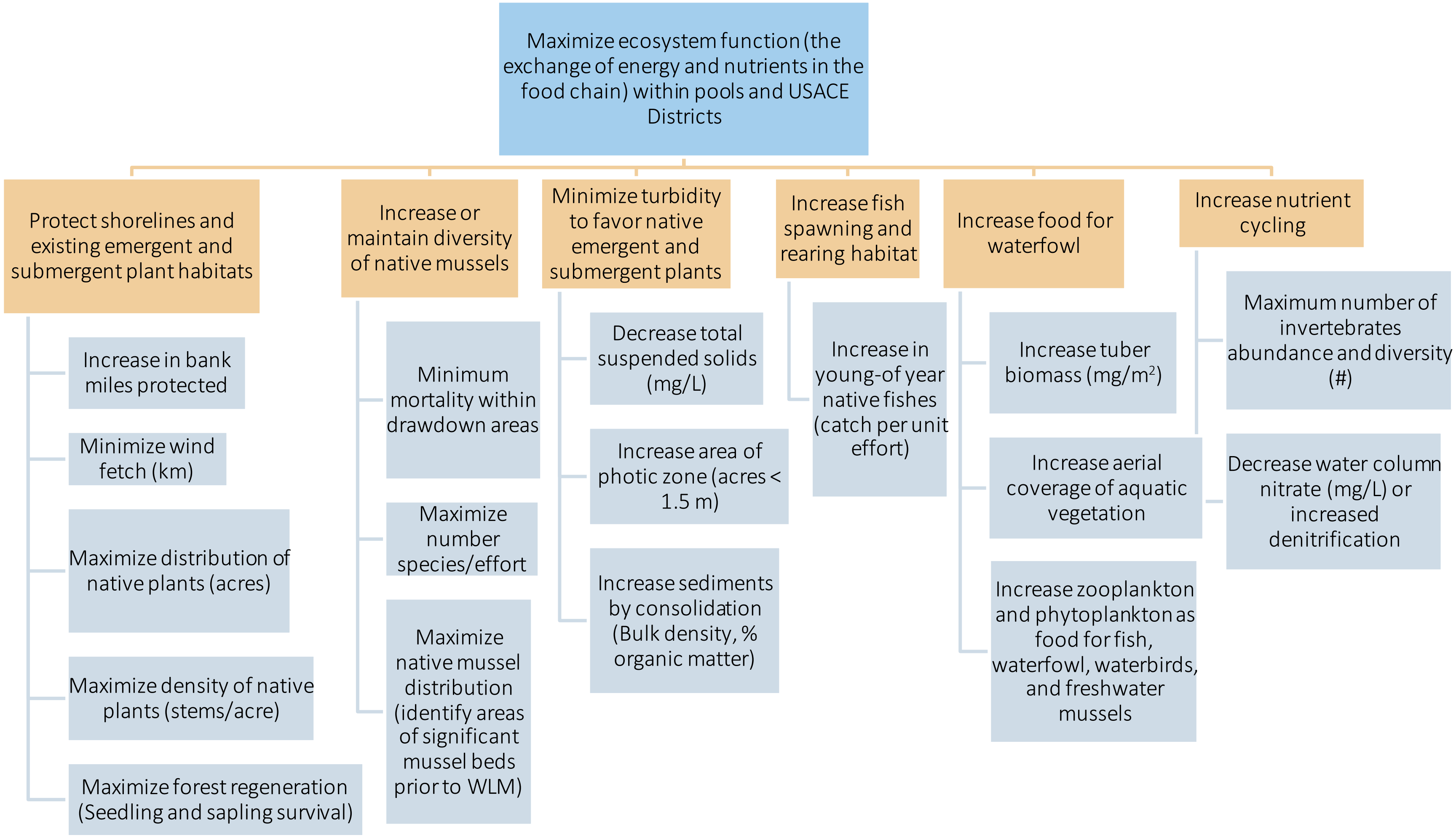


Figure 1a. Objective hierarchies showing connections between fundamental and means objectives. Blue box (first row) is the fundamental objective, gold boxes (second row) are means objectives, and light blue boxes (remaining rows) are possible measures to assess whether and how the ecological objectives are met with WLM. Specific targets or thresholds for quantifying these measures are not yet identified.

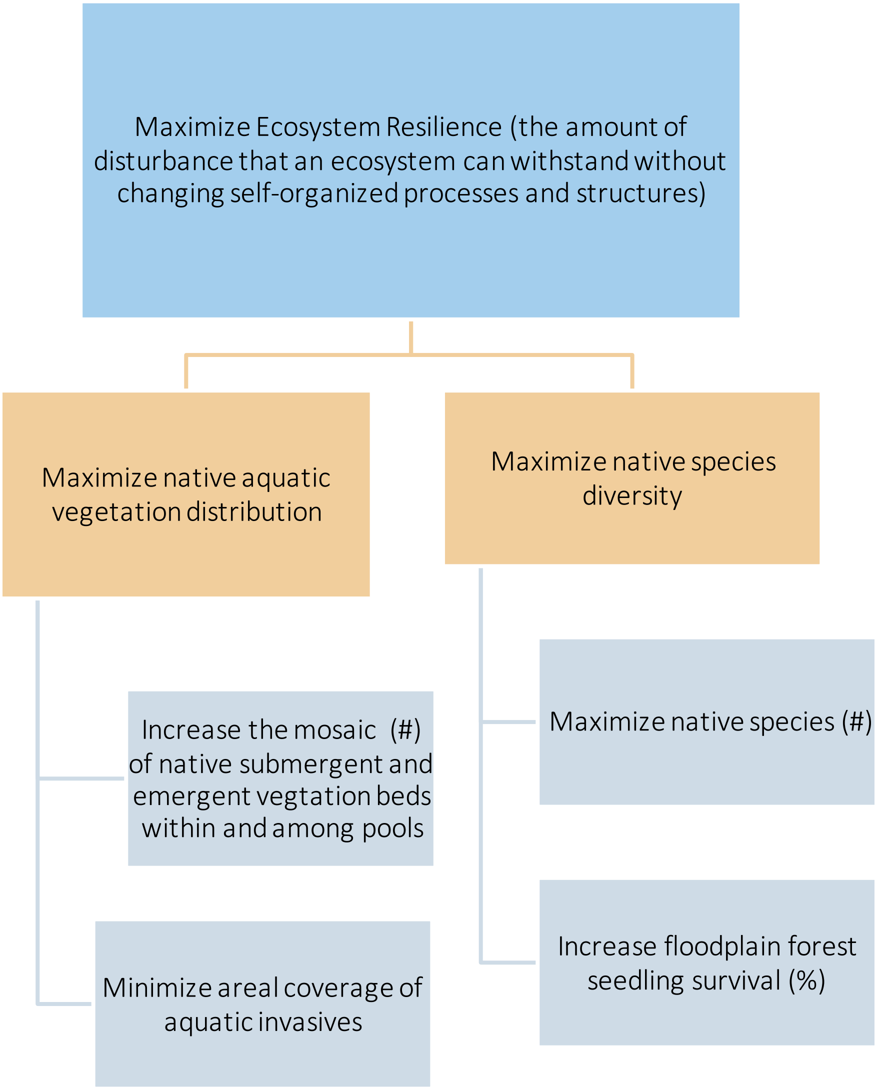


Figure 1b. Objective hierarchies showing connections between fundamental and means objectives. Blue box (first row) is the fundamental objective, gold boxes (second row) are means objectives, and light blue boxes (remaining rows) are measures.

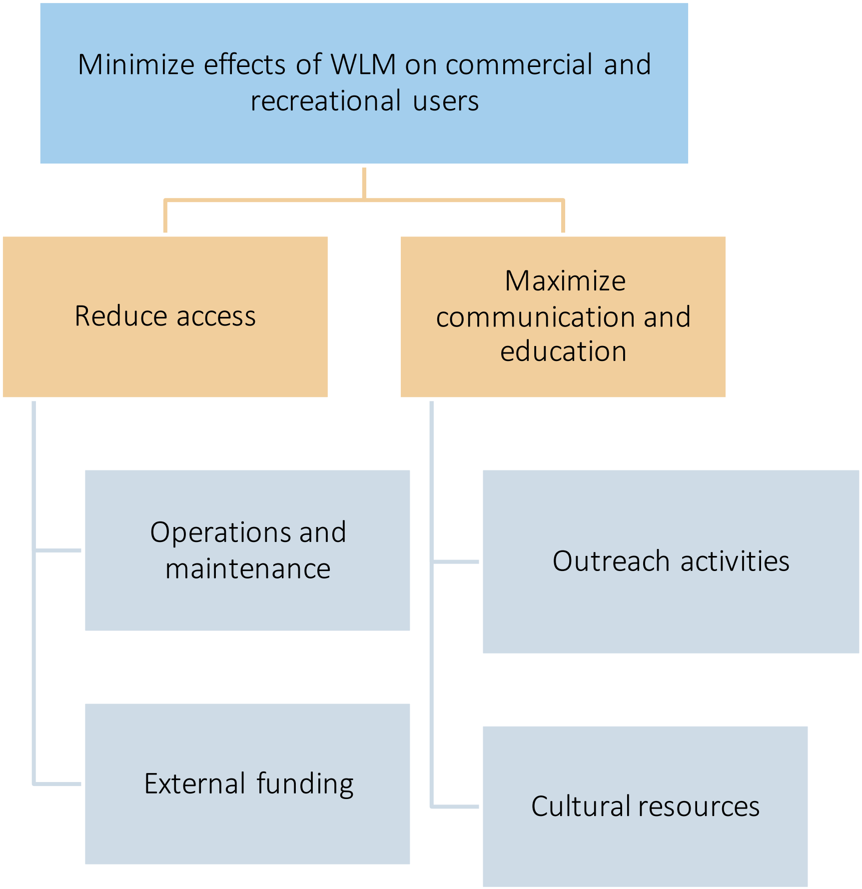
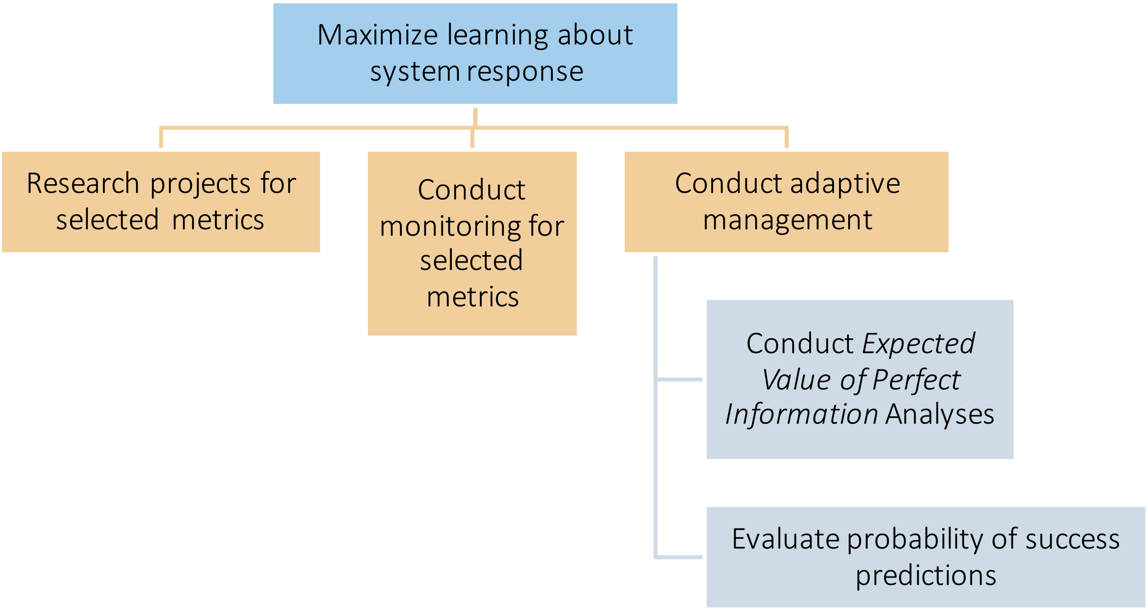


Figure 1c. Objective hierarchies showing connections between fundamental and means objectives. Blue box (first row) is the fundamental objective, gold boxes (second row) are means objectives, and light blue boxes (remaining rows) are measures.



Maximize learning about system response

Research projects for selected metrics

Conduct monitoring for selected metrics

Conduct adaptive management

Conduct *Expected Value of Perfect Information* Analyses

Evaluate probability of success predictions

Figure 1d. Objective hierarchies showing connections between fundamental and means objectives. Blue box (first row) is the fundamental objective, gold boxes (second row) are means objectives, and light blue boxes (remaining rows) are measures.

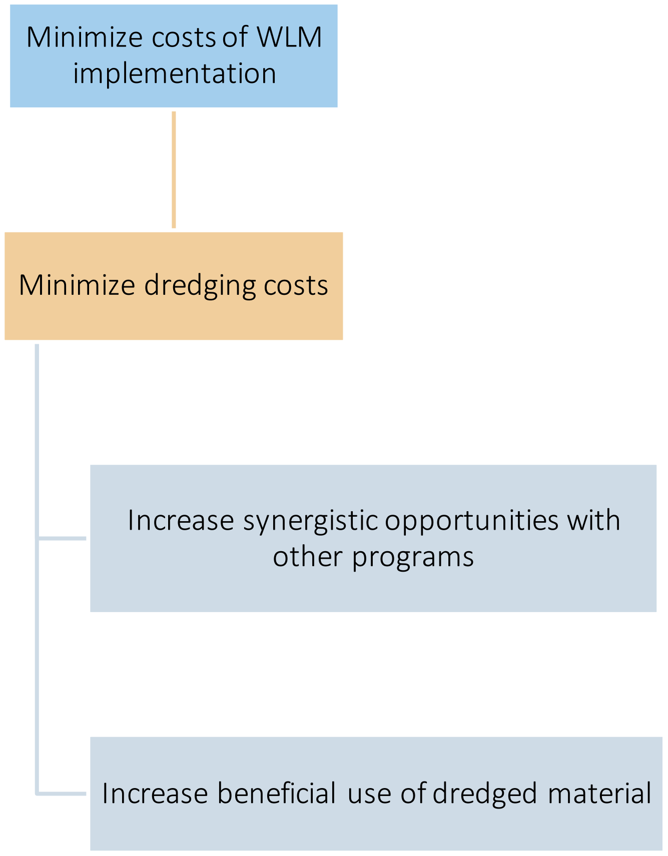


Figure 1e. Objective hierarchies showing connections between fundamental and means objectives. Blue box (first row) is the fundamental objective, gold boxes (second row) are means objectives, and light blue boxes (remaining rows) are options for reducing costs.

Anticipated Outcomes

The *ad hoc* group listed the best and worst outcomes that they could imagine arising from implementing WLM anywhere in the UMRS. Best possible outcomes were identified to inform fundamental objectives. Wort possible outcomes were identified to highlight concerns regarding the implementation of WLM and key uncertainties.

Best Possible Outcomes

- WLM would increase ecosystem resilience in desirable ecosystem states to short- and long-term physical stressors, including the maintenance of native biodiversity
- WLM would induce a regime shift from turbid, unvegetated conditions to clear water, with an abundance of submersed, emergent, rooted floating-leaved, and shrub vegetation types. The vegetation would provide native vegetation assemblages as habitat and food for native fish and wildlife species (Larson et al. 2020, Bouska et al. 2022)
- Allows scientists to assess the long term and short-term effects of how the system responds to WLM. That information could be used in future iterations of prioritization and WLM treatments

Worst Possible Outcomes

- A lack of vegetation and water clarity response and no ecosystem state change, but a large expenditure of financial resources
- Negative responses by sedentary resources (e.g., higher than expected mortality of mussels and submergent plants)
- Failed or aborted WLM due to challenging water levels and/or flow conditions with a large expenditure of financial resources
- Increased invasive species distribution and abundance (e.g., increased non-native flowering rush plants)
- A perceived “failure” of WLM could cause public discouragement, jeopardizing future WLM work. This perception could cause a loss of stakeholder support for future WLM. For example, MVR aborted the Pool 13 drawdown because the reduced water level and gate adjustment resulted in stranded fish (which perished). The fish stranding was visible to the public, creating a public perception challenge, despite the loss of only a few fish (<100, Kirk Hansen, IA DNR, personal communication)
- There remains high uncertainty regarding risks to specific biota of interest, like fish and mussels
- The cost to benefit ratio would be high. For example, there were high costs (time and financial resources) of WLM implementation compared to the ecological benefits
- The frequency of drawdown is uncertain, and frequent drawdowns could cause long-term decrease of biodiversity within a pool

Operationalizing WLM: Focus on Pool Selection

Assessing the Ecological Status of Pools

To realize the fundamental objectives, it was important to determine where to apply WLM within a USACE District. The *ad hoc* group considered how to categorize and select pools within a USACE District for future WLM implementation. Ultimately, each USACE District would have a prioritized list of pools and a process for selection based on their fundamental objectives that would guide WLM for the next 25–50 years.

The *ad hoc* group was asked, "What tells you a pool is in either "good" or "poor" condition and might benefit from WLM?" In general, the primary indicators of pool condition were chosen as the prevalence (the proportion of sites with plants present within a pool) of both submergent and emergent aquatic vegetation. The *ad hoc* group explored a few options for assessing current ecological status. The true ecological condition of individual pools lies along a continuum from well-vegetated to unvegetated, so *ad hoc* group members used prevalence and abundance of aquatic vegetation as indicators.

The *ad hoc* group also brainstormed possible means of assessing pool condition beyond solely using estimates of aquatic vegetation cover. Condition could be assessed by describing ecological state assigned to individual pools from the UMRS' Habitat Needs Assessment II that specified one of three condition levels (McCain et al. 2018). Another possibility is to develop a model like Carhart et al. (2021) whereby vegetation habitat suitability modeling could incorporate measures of water clarity (euphotic zone), river geomorphology, and water level fluctuation to estimate the potential acreage that could support submergents within a pool. This proposed modeling approach could be modified to provide an ordered ranking of pools from worst to best potential response to WLM. Ultimately, the *ad hoc* group strived to keep their scoring of pool condition simple (poor versus good).

The *ad hoc* group defined their own heuristic that could be used to categorize pools into one of two states: "poor" and "good" (see section on Definitions). Here, "good" pools were defined as those where there is aquatic vegetation in each of four growth forms (submersed, floating-leaved, emergent annual, and emergent perennial); when taken together, they provided between 25 – 50 % areal coverage of waters ≤ 1.5 m deep. Pools scoring the highest condition might be those approaching or meeting a 50: 50 aquatic vegetation to open water ratio and those with the lowest score given to pools that have little to no aquatic vegetation (Weller and Spatcher 1965). The *ad hoc* group agreed that defining and describing "good" ecological condition needed refinement, including defining the conditions ranging from 25%– 50% and greater than 50% aquatic vegetation. Recommendation #3 suggests that more discussion and supporting science would help with pool selection criteria. However, the initial definition was enough for the *ad hoc* group to proceed with the structured decision analysis and compare alternatives.

Alternative Approaches for Selecting Pools for WLM

The *ad hoc* group discussed several options for selecting pools for future treatment such that each USACE District would have a list of several pools in queue for treatment with WLM. The *ad hoc* group then brainstormed several options for selecting pools for future WLM. Alternative approaches were focused on improving or maintaining the ecological status, function, and resilience of pools across the UMRS. The *ad hoc* group used a simple multi-attribute rating technique to compare alternative pool selection processes (Barron and Barret 1996). During the final meeting, the decision process was challenged by the uncertainties associated with the full range of ecosystem responses to WLM and differences in values and risk tolerance among the *ad hoc* group and their respective agencies. To overcome this problem, the *ad hoc* group discussed risk attitudes to arrive at a consensus agreement and plan.

The *ad hoc* group proposed that once all pools in a USACE District are assigned an initial condition (prior to WLM), the “WLM teams” develop a list of pools ordered by ecological condition and a list of pools or set of pools to treat with WLM “next” and why. The choice and prioritization only need to be done once and reviewed periodically as more is learned about the system and the ecological conditions of the pools change. The *ad hoc* group suspected that a degraded pool may initially require multiple, successive years of WLM to achieve a desired minimum aquatic vegetation response.

Comparing Alternatives for Pool Selection

Prior to developing alternatives, six performance measures were developed by the *ad hoc* group to compare and rank the alternatives. Constructed scales were used due to time constraints and sometimes a lack of information. All six performance measures were evaluated using the same scaling system.

Scaling system:

1=none (worst),
2=some,
3=many/most,
4=all (best)

Performance measures:

1) Ecosystem function and resilience are improved at a system-scale

2) Ecosystem function and resilience are improved at a pool-scale

3) Eventually all “available” pools are selected

4) A list of pools for planning is provided

5) Pool selection actively supports or improves a pool's current ecological state or condition

6) Costs are associated with the complexity of selection criteria

Summarized List of Alternatives and Associated Primary Considerations and Recommendations

Alternative 1: Select the most degraded pool(s) to address

Ad hoc group concern: This alternative may result in decision-makers always choosing the most degraded pools (because a pool may degrade quickly) and never treating the pools in good condition until their condition degrades.

Alternative 2: Estimate a cost-ecological benefit ratio for each pool. Monetize components and score pools based on financial costs in relation to ecological resilience and function gained

Ad hoc group concern: This alternative requires adding additional fundamental objectives for consideration before the *ad hoc* group can score it against the other alternatives. Monetization of ecological benefits may be challenging. A cost/benefit ratio could be estimated as the areal extent of vegetation increased/cost of dredging.

Alternative 3: Implement a randomized selection process, meaning all pools have equal chance of selection

Ad hoc group concern: This alternative lacks the ability to address pools with a perceived immediate need or pools best suited for WLM at a given time, although it would allow decision-makers to take advantage of opportunities. Recommended combining Alternatives 2 and 3.

Alternative 4. Order pools based on trends in emergent and submergent aquatic vegetation and select those demonstrating negative trends in prevalence or areal extent

Ad hoc group concern: This alternative requires monitoring all pools to determine status and trends, and pools without vegetation would come in first. It puts the *ad hoc* group in a reactive mode rather than in an active mode of consistently trying to promote diversity. Recommended removal of this option.

Alternative 5. Select pools based on opportunity and convenience: e.g., tie WLM to pools with HREPs to save on dredging costs and simplify communications

Ad hoc group concern: Scientific results derived from a judgement sample are not as robust as those based on a random sample, but there are methods to deal with this concern. The a*d hoc* group agreed this alternative may be important to alleviate high costs for some pools. It is the most likely to happen from a practical perspective. Recommended combining 5 and 6.

Alternative 6. Maintain pools currently in "good" condition through regular, recurrent WLM and apply WLM to one new (additional), but degraded pool per year

Ad hoc group concern: Conducting WLM on two or more pools in a year is possible but constrained by funds. This is an effective alternative if funds become available.

Alternative 7. Focus WLM on pools that exceed a set level of total suspended solids (TSS; mg/L) or turbidity (NTU) with the ecological goal of reducing turbidity

Ad hoc group concern: A change in turbidity may be difficult to evaluate and timing of when to measure turbidity is important. Turbidity change will likely occur in and around the fringes of a drawdown area, so sampling locations should be carefully evaluated. Recommended removal of this alternative but instead added TSS to alternative 4.

Alternative 8. Select a set of pools with supporting partners capable and willing to manage implementation and monitoring

Ad hoc group concern: This alternative focuses on the partnership and less on the ecology. The alternative is unclear what partnerships this was referencing. Are these financial partners or certain populations that generally support WLM? Recommended removal of this option.

Alternative 9. Use WLM to restore pools to "good" ecological condition throughout the system because redundancy is a component of resilience

Ad hoc group concern: Alternative 9 would result in the distribution of pools considered in "good" condition all the way down the river and was considered a desirable outcome.

Alternative 10. Select pools with the greatest potential for increasing emergent and submergent aquatic vegetation (e.g., potential measured in acres of increase)

Ad hoc group concern: The focus of this alternative would be bringing pools in "poor" condition up to "good" condition and concern is that pools in "good" condition would not be treated to maintain their "good" condition unless they fall into "poor" condition.

Alternative 11. Use the selection process outlined in Kenow et al. (2016) that considers: Pool regulation type, dredging costs, hydrological limitations, ability to monitor, socio-economic factors, and public support. This alternative may be like, or encompass, alternative 2

Ad hoc group concern: Alternative 11 is expensive and complex.

Final Revised and Agreed Upon Set of Alternatives

Alternative 1. Select most degraded pools first then move on to “good” pools

Alternative 2. Categorize and select pools based on projected cost: benefit ratio where the areal extent of potential vegetation gained exceeds the cost of additional dredging

Alternative 3. Categorize and select pools based on negative trends in aquatic vegetation life forms and
Alternative 4. Categorize and select pools based on opportunity (e.g., Tie WLM to pools with planned HREPs)

Alternative 5. Conduct WLM in pools in “good” condition (e.g., Pools with 25-50% aquatic vegetation in the <1.5 m photic zone) and “poor” condition (<25% aquatic vegetation). Approximately two pools undergo WLM each year, including one in good condition and another in poor condition

Alternative 6. Select pools such that at least 50% of pools in each USACE District are or will be in “good” ecological condition after WLM

Alternative 7. Rank pools based on Kenow et al. 2016 that considers seven factors including surface elevation, area to benefit, dredging costs, hydrological limitations, ability to monitor, socio-economic factors, and public input

Consequences and Tradeoffs

The six performance measures were ranked by each member for each of the seven alternatives in the final set based on their importance to the individual (Barron and Barret 1996, Table 1). Consequences (predicted outcomes of the selection option) and tradeoffs among the alternatives were evaluated using a simple multi-attribute rating technique after Edwards and Barron (1994) and programmed in Microsoft Excel (SMART Tool, Decision Analysis Training Program, National Conservation Training Center, Shepherdstown, WV). Table 1 shows the raw score averages of all participants. The range of scores for each of the performance measures is provided. Normalizing raw scores placed all scores on a 0–1 scale to make them directly comparable; normalized scores (X') were calculated for each objective. Scores were normalized and weighted based on *ad hoc* group member values (Table 2) using the following formulas. When the goal of an objective was to maximize, we used:

$X' = (x - x_{min})/(x_{max} - x_{min})$,
and if the goal was to minimize, we used:
$X' = (x - x_{max})/(x_{min} - x_{max})$,
where x are the original scores from the Table 1a. Columns on the far right provide x_{min} and x_{max} for each objective.

Tables 1a and 1b. Consequences averaged raw scores, ranges of scores, and normalized scores by performance measure and alternative (all participants).

A. Consequences (Original Scores)			**Alternative**							**Range**	
OBJ #	**Performance Measures for Comparing Alternatives**	**Desired Direction**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	x_{min}	x_{max}
1	Ecosystem function and resilience are improved – System	Max	3.00	2.64	3.18	2.45	3.18	3.36	3.18	2.45	3.36
2	Ecosystem function and resilience are improved – Pool	Max	3.64	3.00	3.64	3.00	3.45	3.27	3.36	3.00	3.64
3	Eventually all "available" pools are selected (50-yr timeline)	Max	2.09	2.00	1.91	1.91	3.27	2.73	2.64	1.91	3.27
4	Provides a list of pools for planning	Max	3.18	3.09	2.55	2.73	3.36	3.18	3.45	2.55	3.45
5	Pool selection is proactive in supporting or improving a pool's current ecological state	Max	2.55	2.09	2.73	1.91	3.36	2.82	2.91	1.91	3.36
6	Cost associated with complexity of selection	Min	2.64	2.36	2.64	3.00	2.77	2.18	2.18	2.18	3.00

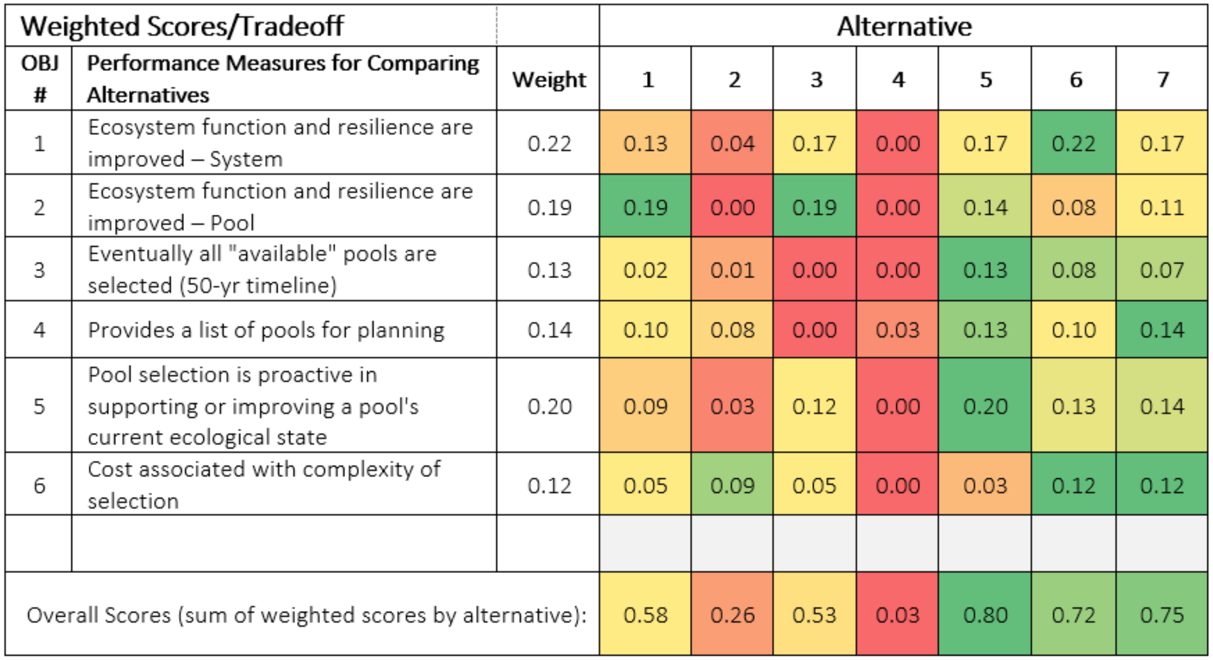
B. Normalized Scores			**Alternative**						
OBJ #	**Performance Measures for Comparing Alternatives**	**Desired Direction**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	Ecosystem function and resilience are improved – System	Max	0.60	0.20	0.80	0.00	0.80	1.00	0.80
2	Ecosystem function and resilience are improved - Pool	Max	1.00	0.00	1.00	0.00	0.71	0.43	0.57
3	Eventually all "available" pools are selected (50-yr timeline)	Max	0.13	0.07	0.00	0.00	1.00	0.60	0.53
4	Provides a list of pools for planning	Max	0.70	0.60	0.00	0.20	0.90	0.70	1.00
5	Pool selection is proactive in supporting or improving a pool's current ecological state	Max	0.44	0.13	0.56	0.00	1.00	0.63	0.69
6	Cost associated with complexity of selection	Min	0.44	0.78	0.44	0.00	0.28	1.00	1.00

Tradeoffs

Weighted Scores

Final scores factor in the weight of importance of each performance measure. The Weight column is based on the *ad hoc* group members' average ranks and scores. Weights are multiplied by normalized scores from the previous table to calculate weighted scores. The sum of weighted scores in each column is the overall score for each alternative. Alternatives with higher overall scores have more support.

Table 2. Tradeoff table. Color shading indicates trade-offs, i.e., which alternative performs best (green) and worst (red) for each performance measure.



Weighted Scores/Tradeoff			Alternative						
OBJ #	**Performance Measures for Comparing Alternatives**	**Weight**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	Ecosystem function and resilience are improved – System	0.22	0.13	0.04	0.17	0.00	0.17	0.22	0.17
2	Ecosystem function and resilience are improved – Pool	0.19	0.19	0.00	0.19	0.00	0.14	0.08	0.11
3	Eventually all "available" pools are selected (50-yr timeline)	0.13	0.02	0.01	0.00	0.00	0.13	0.08	0.07
4	Provides a list of pools for planning	0.14	0.10	0.08	0.00	0.03	0.13	0.10	0.14
5	Pool selection is proactive in supporting or improving a pool's current ecological state	0.20	0.09	0.03	0.12	0.00	0.20	0.13	0.14
6	Cost associated with complexity of selection	0.12	0.05	0.09	0.05	0.00	0.03	0.12	0.12
Overall Scores (sum of weighted scores by alternative):			0.58	0.26	0.53	0.03	0.80	0.72	0.75

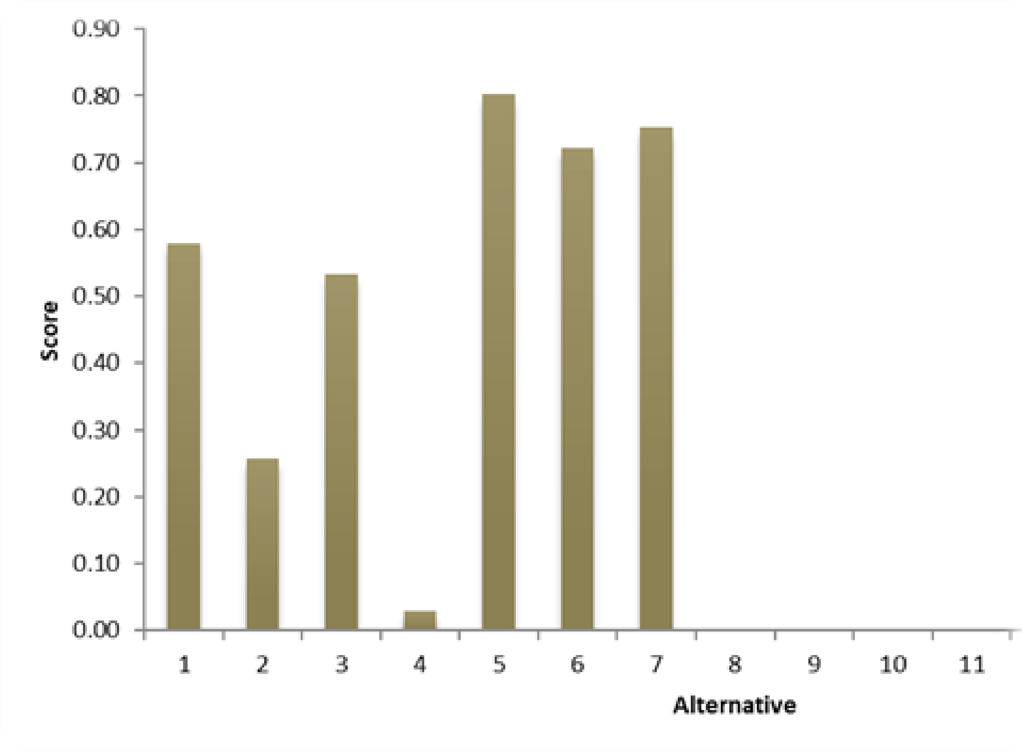


Figure 2. Bar chart of the alternative scores showing Alternative 5 with the highest score. Alternative 5 is to maintain "good" pools (e.g., Pools with 25–50% aquatic vegetation in the <1.5 m photic zone) and add one degraded pool during each WLM treatment. Alternatives 8–11 were removed during the final ranking as the a*d hoc* group determined they were not viable alternatives for further consideration.

Outcomes and Next Steps

Alternative 5 was the highest ranked alternative by the *ad hoc* group, which was to maintain "good" pools (e.g., Pools with 25–50% aquatic vegetation in the </= 1.5 m photic zone) and apply WLM to one degraded pool such that two pools are treated in each District approximately each year. Alternatives 6 and 7 were very close in rank to 5.

At the end of the workshop, the participants agreed: 1) WLM can serve as an effective restoration tool to meet the fundamental objectives described herein, and 2) there is evidence, though somewhat limited, regarding the importance of WLM in maintaining pools in "good" ecological condition.

When reflecting on the initial results, a critical uncertainty was raised within the a*d hoc* group. Specifically, there was some disagreement within the a*d hoc* group regarding the treatment of "good" pools, with the benefits of applying WLM to pools currently in "good" ecological condition unclear. There is limited evidence regarding the effects of WLM in the unique riverine floodplain ecosystem of the UMRS, especially in areas already in good condition. Whereas concern was raised about "overtreating" pools already considered "good" that may cause ecological degradation or high cost, the notion was also raised that reintroducing low water variability via WLM may provide worthwhile ecological benefits to pools in good condition.

Participants discussed the phenomenon of periodic, albeit rare, low water conditions during the growing season had resulted in naturally variable low water levels, suggesting that WLM may not be needed in some years to achieve aquatic vegetation goals. However, the ecological benefits of drawdowns may only last a few to several years, and the repeated disturbance by WLM may be needed to maintain pools in "good" condition. Targeted research or adaptive management is needed to better understand the effects of natural hydrologic fluctuations and drawdowns on the prevalence and productivity of key aquatic plant species and additional ecological effects.

Prior to conducting WLM in a single pool in either "good" or "poor" condition, the a*d hoc* group and newly formed District "WLM teams" should work with a decision analyst to investigate which key uncertainties regarding ecological effects are most important for making future decisions regarding operationalization of WLM. Fundamental to this question is the degree to which more information will improve confidence in future application of WLM to pools in "good" condition. There was no dispute that WLM has potential to improve the ecological condition of pools in degraded condition, but uncertainties remain of whether drawdowns in good condition pools would have benefits or would do unintentional harm. A trained decision analyst who is familiar with adaptive management, value of information analyses, and risk analyses, should work with the *ad hoc* group to clarify what specific information will provide them with greater confidence in deciding whether to implement WLM in pools that are already in good condition. This same analyst should work with scientific experts and the *ad hoc* group to develop research projects or use adaptive monitoring and management to address critical uncertainties. Value of information analysis considers the effects of reducing or eliminating uncertainty (Canessa et al. 2015, Maxwell et al. 2015; Smith 2020) and is best led by a decision analyst in close cooperation with the *ad hoc* group and associated scientists. If the results from implementation in a couple of good pools fails to show any reduction in uncertainty, the WLM teams will want to re-evaluate before proceeding to conduct more WLM in "good" pools. It is important to note that some uncertainty will always remain and, at a minimum, will need to be accounted for in future decisions as will the risk tolerance of each partner agency. Continued decision analysis is critical to working through the uncertainty prior to any future application of WLM.

Ultimately, the *ad hoc* group agreed to select one vegetated pool (from among pools considered in "good" condition) in all three Districts to implement WLM as part of a controlled, thorough, and objective scientific evaluation. The *ad hoc* group agreed that USGS should lead the design of the investigation with the aid of a trained decision analyst. The *ad hoc* group seeks improved confidence regarding when and how WLM might affect species diversity and vegetative abundance (e.g., areal extent, seed, and tuber biomass) as well as what additional ecological costs and benefits might be expected (see Fundamental Objectives and Fig. 1a – 1d). Future studies should also examine recolonization of submergent vegetation after water levels return and continue for several years. Reducing uncertainty may be achieved by learning how key state variables and ecological functions respond to WLM (e.g., number of species, areal extent by plant growth form, seed and tuber biomass, turbidity, total suspended solids, shoreline protected, denitrification, fish spawning and rearing, floodplain forest seedling survival, etc.). The same prediction-learning framework should be followed for WLM conducted in pools in "poor" condition as well. Following this path would advance the scientific understanding of the ecological effects of WLM, help resolve the primary uncertainties within the *ad hoc* group, and aid operationalization of WLM in the UMRS.

Conclusions

The SDM process helped the *ad hoc* group (as river restoration practitioners and scientists) clarify their fundamental objectives for WLM as a restoration tool and to articulate fears if WLM resulted in a poor outcome. The process allowed the *ad hoc* group to acknowledge their concerns and reach an agreement on a best path forward. The primary recommendation is to compile and evaluate insights gained from WLM that is thoughtfully applied to select pools both in "good" and "poor" conditions. By implementing WLM coupled with learning, we can better understand which fundamental and means objectives can be fulfilled from WLM in this unique, large river floodplain system. The initial knowledge gained from WLM trials, as well as more SDM analyses, can further guide recommendations for effective operationalization of WLM in the UMRS.

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Appendix 1

The WLM Regional Coordinating Committee (RCC) was formed in 2018. An initial workshop in 2018 was centered on creating a unified purpose including vision and mission statements to advance water level management (WLM) in the Upper Mississippi River System.

Vision and Mission for the WLM Regional Coordinating Committee

Workshop attendants were organized into six groups to brainstorm a mission and vision statement for the WLM RCC. Each group shared their statements and then participants discussed the overarching themes. Ultimately, participants agreed to the following statements:

- Vision: Improve ecological health and resilience through optimal water level variation
- Mission: To promote systemic, routine, and coordinated water level variation, address policies and funding needs, advance interdisciplinary monitoring and research, and inform and engage the public.

Appendix 2

Ecosystem state variables can identify current conditions of the river. These variables, brainstormed by the *ad hoc* group, can define the ecological state of the pools, and potentially signal the need for WLM, or be used as metrics for assessing WLM success of meeting ecological objectives.

State variables with focus at a pool-scale:

1) Water quality
    a) Total phosphorus concentrations
    b) Chlorophyll a concentrations
    c) Water clarity (turbidity, suspended solids, and light penetration)
2) Vegetation
    a) Prevalence (% frequency of occurrence, % cover)
    b) Abundance (density estimates)
    c) Diversity (primarily at the pool scale; species and life forms)
    d) Free-floating plant dominance
    e) Emergent perennial plants
3) Floodplain forests
    a) Bank erosion
    b) Dead, falling trees (particularly mature silver maples)
4) Fish
    a) Abundance (population estimates)
        - For example, Burdis et al. 2020 observed that yellow perch increased after low water years because they need aquatic plants and benefits anglers
5) Waterfowl and waterbird use
    a) Spring and fall migration
    b) Species vary spatially, but canvasbacks and scaup are likely indicator species

Appendix 3

Fundamental Objective: minimize costs and disruption to users

1) Acknowledge many users:
    a) Commercial navigation
    b) Homeowners with shoreline
    c) Owners of boat houses
    d) Barge terminals
    e) Municipalities (e.g., waste discharge, water supply)
    f) Hydropower (Pool 15, others?)
    g) Recreation users (waterfowl and waterbird hunters, fishermen, boaters, swimmers)
    h) Marinas
    i) Power plant and other Facility cooling

2) What are the "disruptions"?
    a) Aesthetics (e.g., mud flats are concerning for some people, fish kill)
    b) Economic (e.g., municipalities, hydropower, recreation expenditures)
    c) Social (e.g., perceptions, gathering for recreation, fish kill, etc.)

3) Indicators of success that minimizes disruptions to users
    a) Ask users before drawdown (e.g., call municipalities)
    b) Minimal bad press and social media posts, complaints, phone calls to state offices
    c) Social survey for feedback during or after WLM

4) Ways to minimize disruptions (incorporate into alternatives?)
    a) Move boat ramps
    b) Outreach and communication prior to WLM for awareness, promote benefits
    c) Consult existing social surveys, case studies in the WLM Outreach and Communication Plan, prior experience in P5 and P8 and P24-26
    d) Place dredge material in sites scoped for ecological benefits
    e) Advance dredging in high use areas or navigation channel
    f) Revise water control manuals