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PROCESS, POLICY, AND IMPLEMENTATION OF POOL-WIDE DRAWDOWNS ON THE UPPER MISSISSIPPI RIVER: A PROMISING APPROACH FOR ECOLOGICAL RESTORATION OF LARGE IMPOUNDED RIVERS

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ABSTRACT

The Upper Mississippi River (UMR) has been developed and subsequently managed for commercial navigation by the U.S. Army Corps of Engineers (USACE). The navigation pools created by a series of lock and dams initially provided a complex of aquatic habitats that supported a variety of fish and wildlife. However, biological productivity declined as the pools aged. The River Resources Forum, an advisory body to the St. Paul District of the USACE, established a multiagency Water Level Management Task Force (WLMTF) to evaluate the potential of water level management to improve ecological function and restore the distribution and abundance of fish and wildlife habitat. The WLMTF identified several water level management options and concluded that summer growing season drawdowns at the pool scale offered the greatest potential to provide habitat benefits over a large area. Here we summarize the process followed to plan and implement pool-wide drawdowns on the UMR, including involvement of stakeholders in decision making, addressing requirements to modify reservoir operating plans, development and evaluation of drawdown alternatives, pool selection, establishment of a monitoring plan, interagency coordination, and a public information campaign. Three pool-wide drawdowns were implemented within the St. Paul District and deemed successful in providing ecological benefits without adversely affecting commercial navigation and recreational use of the pools. Insights are provided based on more than 17 years of experience in planning and implementing drawdowns on the UMR. Copyright © 2015 John Wiley & Sons, Ltd.

KEY WORDS: drawdown; navigation pool; restoration; upper Mississippi River; water level management

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INTRODUCTION

The Upper Mississippi River (UMR) is defined as the 1462-km main stem stretch of the Mississippi River between St. Anthony Falls in Minneapolis, Minnesota, and its confluence with the Ohio River at Cairo, Illinois (Fremling and Claflin, 1984; Wiener *et al.,* 1998). This river ecosystem has long been recognized as a nationally significant resource for fish and wildlife. In 1924, Congress formally acknowledged the ecological significance of the UMR and its floodplain with establishment of the Upper Mississippi River National Wildlife and Fish Refuge (Public Law 268). The 972-km^2 refuge, which extends from Rock Island, Illinois, to Wabasha, Minnesota, and other floodplain wetlands were designated as a Wetland of International Importance by the Ramsar Convention in 2010 (Ramsar, 2013). The Water Resources Development Act of 1986 reaffirmed the importance of this floodplain for fish and wildlife habitat when it formally declared the UMR a nationally significant ecosystem (Public Law 99-962).

The UMR is also recognized as a nationally significant commercial navigation system (Public Law 99-962). A series of 29 lock and dams were constructed by the U.S. Army Corps of Engineers (USACE) in the 1930s to maintain a 2.7-m commercial navigation channel (Figure 1). The free-flowing UMR was transformed into a series of shallow navigation pools, yet upper portions of the pools maintained much of the pre-dam geomorphic complexity. The locks and dams maintain high and relatively stable water levels during low-flow periods, especially late summer through winter, compared to pre-lock and dam conditions. During flood

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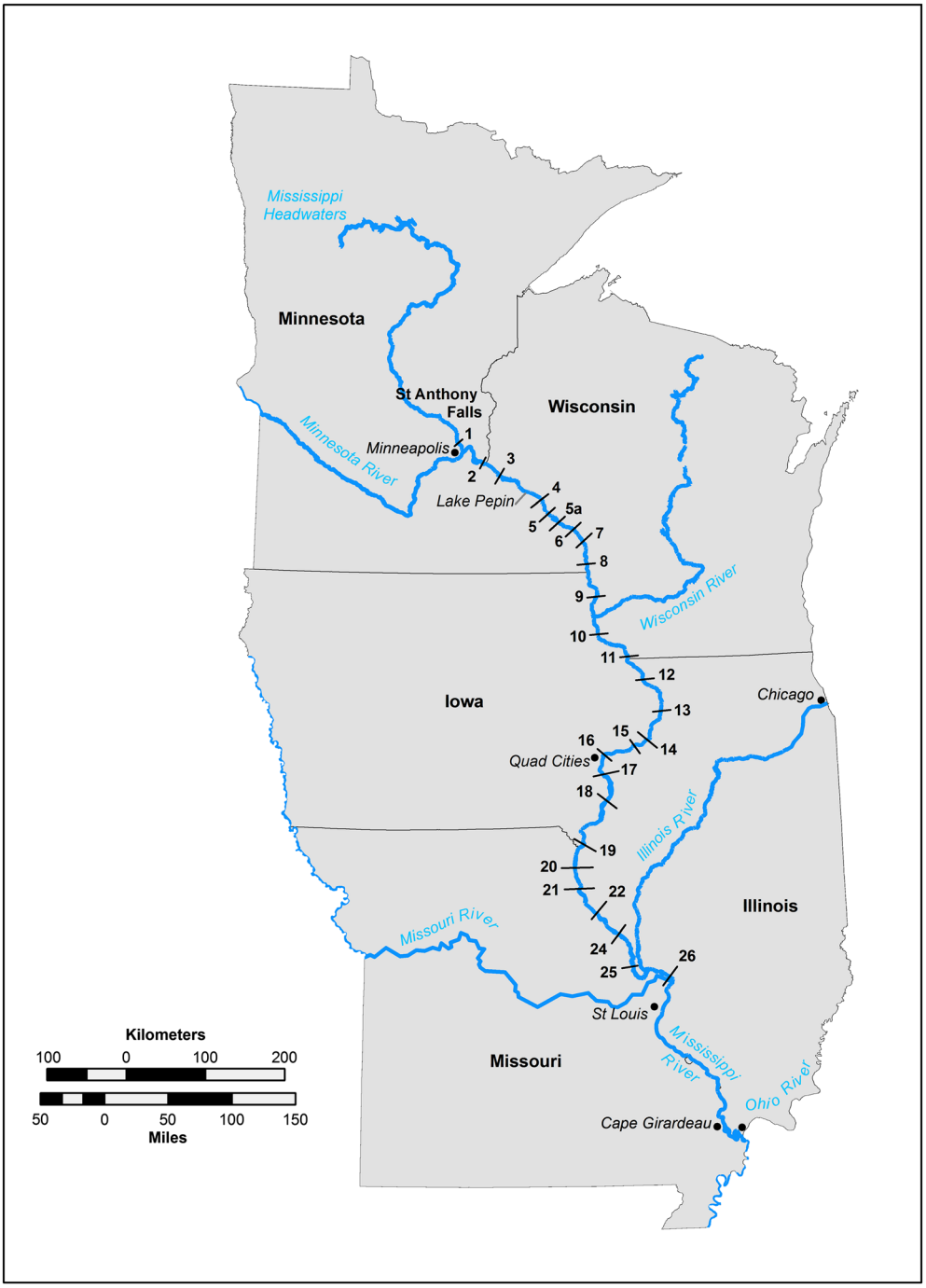

Figure 1. Map of the Upper Mississippi River showing the approximate locations of lock and dam numbers 1–26. (Note: there is no Pool 23). This figure is available in colour online at wileyonlinelibrary.com/journal/rra

events, dam gates are raised completely out of the water to allow floodwaters to pass in a manner that allows for some of the dynamic processes of a large river flood pulse. However, most of the time, the river system is impounded, and water levels are maintained at elevations about 1.5 to 6.1 m higher than pre-dam conditions (Wilcox *et al.,* 2004).

The navigation pools (pools) that resulted from the artificially maintained high water levels were initially structurally diverse and supported a rich variety of fish and wildlife (Wiener *et al.,* 1998). Over time, alteration of the hydrologic regime, island loss via erosion, increased sedimentation, formation of unconsolidated substrates, and sediment resuspension

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through wind and wave action impacted the distribution and abundance of aquatic vegetation (Peck and Smart, 1986; Fischer and Claflin, 1995; Wiener *et al.,* 1998). Consequently, habitat quality in these pools was degraded and large expanses of open water with little aquatic vegetation developed (as illustrated in Figure 2) that were less beneficial to fish and wildlife (Lubinski *et al.,* 1993; Fremling, 2005).

Following a notable decline in aquatic vegetation during the late 1980s (Weiner et al., 1998), natural resource managers began discussing options for habitat rehabilitation and restoration on the UMR. Habitat rehabilitation and enhancement projects (including building islands to reduce wind fetch, dredging backwaters, improving shoreline, installing structures to divert water flows, and water level management) were initiated under the Environmental Management Program (created under the Water Resources Development Act of 1986) to counteract the effects of an aging impounded river system by changing the river's floodplain structure and hydrology. While many of these projects met their objectives, their site specific scale and design were not focused on restoring ecological function and process at a pool- or reach-scale (Theiling, 1995; U. S. Army Corps of Engineers, 1996; Delong, 2010).

Water level management, especially water level reduction during the growing season (drawdown), was identified as a promising tool to restore some of the natural processes (i.e. aspects of the historic seasonal hydrograph pattern) of the UMR (U. S. Army Corps of Engineers, 1996). Water level manipulation, including drawdown, has been widely used to manage freshwater marshes for the benefit of wildlife (Harris and Marshall, 1963; Weller, 1978; Fredrickson and Taylor, 1982). Seasonal drawdowns have been conducted for ecological benefits on managed river systems, including restoration of

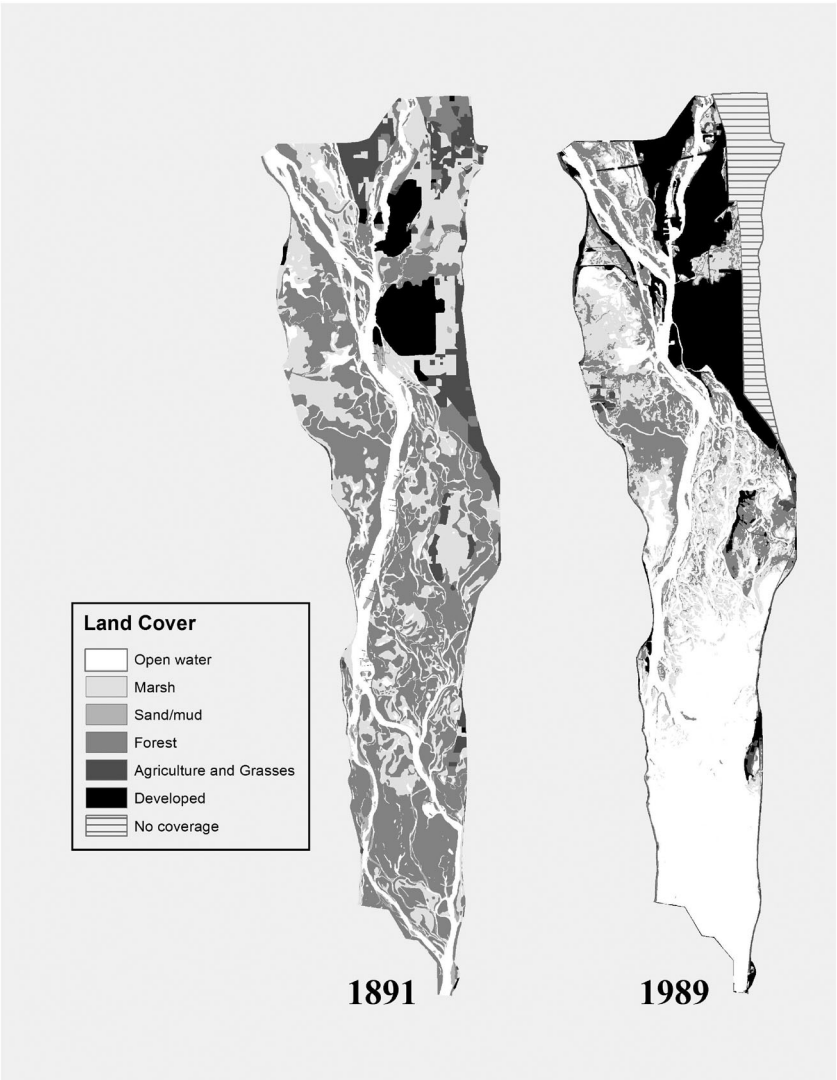

Figure 2. Changes in land cover between pre-dam (1891) and post-dam era (1989) in Pool 8 of the Upper Mississippi River

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riparian habitat (Bhattacharjee *et al.,* 2006), establishment and growth of desirable aquatic vegetation and improved sediment conditions (Theiling, 1995; Woltemade, 1997; Wlosinski *et al.,* 2000), and management of invasive or other undesirable species (Tucker *et al.,* 1997; Bhattacharjee *et al.,* 2006).

In 1994, the USACE in coordination with local, state, and federal natural resource managers completed the first experimental drawdown on Pool 25 with a 0.6-m reduction at the dam for about 30 days during the growing season. This drawdown was followed by a slow rise back to 'full pool.' Moist soil plants responded to the drawdown and when flooded provided habitat and food for fish and wildlife (Garvey *et al.,* 2003). This water level manipulation was within the USACE existing operating range and authority, so there were no impacts to marinas, boat landings, and commercial fleeting sites, which had been constructed to accommodate the entire operational range (about 1.5 m).

Encouraged by results of the Pool 25 drawdown, natural resource managers and scientists wanted to evaluate the potential for water level management as a restoration tool on other reaches of the UMR. This paper provides a comprehensive summary of the process involved in evaluating water level management alternatives and implementing pool-wide drawdowns in the USACE St. Paul District (CEMVP).

TASK FORCE ORGANIZATIONAL STRUCTURE

An evaluation of water level management as a restoration tool was conducted by the Water Level Management Task Force (WLMTF) of the River Resources Forum, an advisory body to the CEMVP formed to offer recommendations and coordination on river-related issues. The WLMTF was established as a technical advisory group in 1995. Representatives include the CEMVP, U.S. Fish and Wildlife Service, U.S. Geological Survey, U. S. Coast Guard, Iowa Department of Natural Resources, the Minnesota Department of Natural Resources and Department of Transportation, and the Wisconsin Department of Natural Resources and Department of Transportation. Membership was also extended to the commercial navigation industry, the public, and non-governmental organizations. The WLMTF provided an effective forum to address issues related to water level management. While participating organizations could vote, the task force usually reached consensus on management decisions.

CONSIDERATION OF MANAGEMENT OPTIONS LEADS TO FOCUS ON POOL-SCALE DRAWDOWN

With funding and technical support from the CEMVP, a Problem Appraisal Report was completed which identified opportunities to improve ecological conditions on the UMR through water level management. Of the eleven management alternatives outlined in the Problem Appraisal Report, winter operation was the first addressed. Historically, pools were drawn down 7.6 cm during November to expedite passage of ice jams the following spring. This affected fish and furbearers which require deeper areas during winter. Based on recommendations from the WLMTF, in 1996 the CEMVP discontinued winter drawdowns and made permanent modifications to its lock and dam operational plans.

Other high priority alternatives involved water level drawdowns during the growing season to improve conditions for the growth of aquatic vegetation and consolidation of sediments through exposure and drying (U. S. Army Corps of Engineers, 1996). Pool 8 was selected as the initial study pool, primarily because of a wealth of existing data on bathymetry, sediment type distribution, and expected benefit to aquatic vegetation. Water level management alternatives (Table I) were identified and limited analyses were conducted including potential impacts on hydrologic and hydraulic changes, water quality, system ecology, lock and dam operations, channel maintenance, commercial navigation, transportation infrastructure, water appropriations, and real estate. Each alternative was categorized as high, medium or low priority based on its potential to provide ecological benefits, ease of implementation, and expense (U. S. Army Corps of Engineers, 1996).

The WLMTF and CEMVP implemented small-scale demonstration drawdowns in 1996 through 1999 at three sites to assess the effectiveness of drawdown as a management tool on the UMR. Sandbags or dikes were used to isolate and pumping used to dewater limited areas on three small backwaters in Pool 5 (Small Bay West and Lizzy Paul's Pond) and Pool 9 (Peck Lake). These drawdowns each promoted improved abundance and diversity of aquatic vegetation (Table II). These results, coupled with the Problem Appraisal Report, prompted the WLMTF to plan drawdowns on a pool-wide scale.

Pool-wide summer growing season drawdowns of 0.3–0.9 m offered the greatest potential for large scale habitat benefits and could possibly be implemented in many pools without substantial adverse effects on river resources and users (U. S. Army Corps of Engineers, 1999).

A pilot pool-scale drawdown was pursued by the WLMTF with the following goals:

(1) improve conditions for the growth of aquatic vegetation with special emphasis on perennial emergent species,
(2) provide a safe navigation channel for use by commercial transportation vessels and barges,
(3) minimize adverse effects on river resources and river users to a level acceptable to the public, and
(4) increase the level of knowledge concerning the effects of pool drawdown to support future management decisions.

PLANNING AND IMPLEMENTATION OF POOL-SCALE DRAWDOWNS

A flow chart outlining the process of planning and implementation of pool-scale drawdowns is provided in Figure 3.

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Table I. Water level management alternatives considered by the Water Level Management Task Force for implementation on Navigation Pool 8, Upper Mississippi River (from U. S. Army Corps of Engineers, 1996)

Alternative	Description/objective	Assigned priority[a]
Mid-term growing season drawdowns (pool-wide)	Expose substrate during 1–2 months of the growing season to promote the growth of annual and perennial emergent aquatic plants and consolidate sediments.	High
Long-term drawdowns (pool-wide)	Draw down water levels for the entire growing season or longer (e.g. through following growing season) to promote aquatic plant growth and sediment consolidation.	High
Small-scale measures (site-specific)	Temporary isolation and drawdown of small waterbodies with option of infrastructure to expedite regular drawdowns for the purpose of establishing or increasing vegetation extent and to consolidate sediments.	Medium
Medium-scale measures (site-specific)	Temporary isolation and drawdown of larger waterbodies with option of infrastructure to expedite regular drawdowns for the purpose of establishing or increasing vegetation extent and to consolidate sediments.	Medium
Discontinue winter drawdowns (pool-wide)	Discontinue 7.6-cm drawdown over winter to provide greater water volume in backwater areas to reduce depletion of dissolved oxygen. Implemented in winter 1995–96.	Medium
Regulate on the high or low side of the regulating plan (pool-wide)	Conscious attempt to regulate pool levels on the high or low side of the ±6.1 cm regulating band to improve habitat conditions for target organisms, control undesirable vegetation, and promote growth of desired vegetation.	Medium
Change in primary control point from mid-pool to the dam (pool-wide)[b]	Pool 8 operates under a mid-pool primary control point for flows $\leq 651\ m^3 s^{-1}$ and under secondary control at the dam when flows exceed $651\ m^3 s^{-1}$. Conversion to dam point primary control would more closely replicate natural river water level fluctuations, which would benefit aquatic habitat.	Medium
Modify discharge through the dam gates	Manage distribution of flow across face of the dam to improve riverine habitat below the dam. This alternative would also require automatic gate adjustment in the lock house or an extra staff person 24 h a day to implement.	Low
Increase the frequency of gate adjustments	Smooth out the daily fluctuations in flow through dam gates to reduce the frequency and amplitude of short-term water level fluctuations to enhance conditions for vegetation growth. It would require automatic gate adjustment in the lock house or an extra staff person 24 h a day to implement.	Low
Spring pool raises (pool-wide)	Raise water levels during springs with low river discharge to improve conditions for species that use flooded habitat for spawning.	Low
Winter drawdowns (pool-wide)	Dewater backwater areas to consolidate sediment and potentially provide access to areas for habitat construction. The adverse effect on fish and furbearers would be substantial. Additionally, this action would be in direct conflict with the Anti-Drawdown law of 1948.	Low

[a]High priority alternatives were believed inexpensive to implement and were expected to provide significant habitat benefits. Therefore, after the completion of the Problem Appraisal Study (U. S. Army Corps of Engineers, 1996), these alternatives became the focus of the work of the task force. Medium priority alternatives may hold promise for the future but were deemed costly to implement. Low priority alternatives may be considered in the future, but limited fiscal and human resources were believed best applied to other alternatives.
[b]See Wlosinski and Hill (1995) for background on control points.

Pool regulation for commercial navigation

A bit of background on regulating the water surface elevation of UMR pools will help set the stage for understanding the complexities of implementing a pool-wide drawdown and modifying reservoir operating plans. Water surface elevations of UMR pools are regulated using target rule curves based on water levels at the dam and at a specific location (control point). Control points are generally located immediately upriver of the dam or at mid-pool. Pool levels are regulated over a range of river discharge (control range) to maintain a target water level at the control point. In some pools, target surface elevations and control points may change with level of discharge.

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Table II. Results of small-scale drawdowns of backwater areas conducted on the Upper Mississippi River

Pool, within-pool location	Size of backwater	Year of drawdown	Duration of drawdown	Response	Source
Pool 5, Small Bay West	2.5 ha	1996	45 days; mid-July through late-August	Plant taxa diversity increased including a 10% increase in emergent species, no change in submersed aquatic species, and 10% reduction in floating-leaved aquatic species	Winkelman J. 1997. *Vegetation Survey of Small-Scale Drawdown in Pool 5*. 8pp.
Pool 5, Lizzy Paul's Pond	21 ha	1997	98 days; 24 June – 30 September	Moist soil vegetation increased 8.3%, emergent vegetation increased 6.5%, and submersed aquatic vegetation decreased 13.6%.	Kenow KP, Hines RK, Lyons JE, Stancill J, Robinson LR. 2001a. *Vegetation Response to an Experimental Drawdown on Pool 5 of the Upper Mississippi River*. Report to U.S. Army Corps of Engineers St. Paul District, 21 Aug 2001; 35pp.
Pool 9, Peck Lake	6.1 ha	1998 1999	50 days; 20 July – early September 90 days; 02 July – late-September	Vegetation development on exposed mudflats was limited due to the late start date, most plants were dwarfed in size, and seed and tuber production were poor. Conditions were favorable for broadleaf arrowhead (*Sagittaria latifolia*) and growth of plants from tubers produced during 1998 increased 140–180%. Tuber production was 692% higher than that measured in 1998. Pre-drawdown aerial photography from 1996 indicated less than 5 percent emergent and less than 2 percent floating-leafed vegetation. The arrowhead established following drawdowns did not persist past 2000 (K. P. Kenow, Unpublished data), but the experience highlighted the importance of multi-year drawdowns on establishment of emergent aquatic perennials.	Kenow KP, Hines RK, Lyons JE. 2001b. *Vegetation Response to an Experimental Drawdown on Pool 9 of the Upper Mississippi River*. Quick Response Report to Region 3, U.S. Fish and Wildlife Service, 10 Jan 2001; 34pp.

The slope of the water surface profile of navigation pools is dependent on river discharge. At extreme low discharge, the pool water surface profile becomes flat. The slope of the water surface profile increases with increasing discharge. The water surface tends to pivot around the primary control point. This characteristic provides for the opportunity to carry out a drawdown that impacts the lower portion of the pool, yet maintains a 2.7-m channel for commercial navigation throughout the entire pool, given adequate flow. During high river discharge events, dam gates are raised from the water and the river assumes 'open river conditions' where the water surface profile is affected only by the constriction of flow (swellhead) associated with the dam.

Factors considered in regulating water surface elevations in navigation pools include regulation method (i.e. control point regulation), estimation of change in storage, gate ratings, inflow estimates, flow routing, and wind effects. Even though the lock and dam system was designed to maintain pool levels to promote a navigation channel of 2.7 m, periodic maintenance dredging is required. Land and water areas were acquired by the Federal government for the Mississippi River 2.7-m Channel Navigation Project (and in conjunction with establishment of the Upper Mississippi River National Wildlife and Fish Refuge) through fee title. Flowage easements were also obtained to permit intermittent flooding of non-federal property by intentional regulation of lock and dams. There are also a number of legal constraints placed on regulation of river discharges and pool elevations (Table III). The USACE has responsibility for water control on the UMR. A Master Regulation Manual for Mississippi River 2.7-m Channel Projects (1969, revised in 1981) provided reference and guidance for the development of manuals for the operation of individual navigation dams.

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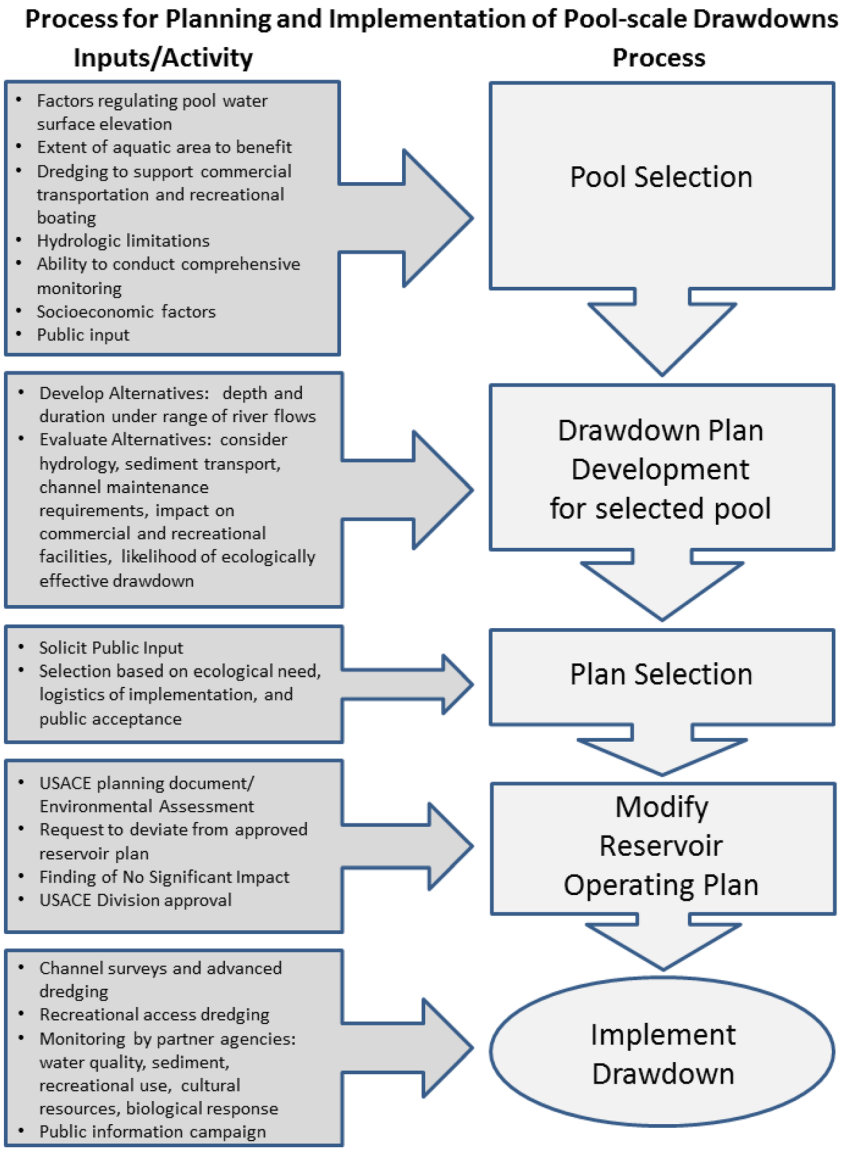

Figure 3. Process flow chart for planning and implementation of pool-scale drawdowns on the Upper Mississippi River. This figure is available in colour online at wileyonlinelibrary.com/journal/rra

Pool selection

The UMR pools in the St. Paul District were evaluated to determine which might be the best candidates for drawdown. The initial screening considered the extent of aquatic area that would benefit from a drawdown, estimates of dredging needed to provide for commercial and recreational navigation, hydrologic limitations, ability to conduct comprehensive monitoring, and unique socioeconomic factors. This process yielded Pools 5, 7, 8, and 9 as the best candidates for the first demonstration drawdown (U. S. Army Corps of Engineers, 1999).

The next step in pool selection required public input. A series of three public meetings were held to provide information about the benefits of drawdown and how social impact, mostly recreational, would be minimized. Based on public feedback, it was determined that recreational concerns could be managed and there was support for the need to improve the ecological condition of Pools 5 and 8. Ecological need, logistics of implementation, and public acceptance led the WLMTF to select Pool 8 for the first demonstration drawdown.

The drawdown of Pool 8 would potentially expose 970–2260 ha of substrate depending on depth of drawdown and discharge. The likelihood of having suitable discharge conditions for drawdown in any given year was relatively high (34%). The amount of dredging required to maintain the main channel was relatively low (61 164 m^3) and disposal of dredged material was manageable. The majority of recreational and commercial facilities were in the upper

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Table III. Legal constraints placed on regulation of river discharges and pool elevations on the Upper Mississippi River

Constraint	Authority
Administration of federal lands for refuge purposes.	Interagency agreement with the USFWS
Legal requirement to maintain the 2.7-m navigation channel.	Rivers and Harbor Act, 1930
USACE policies and procedures for water control management.	33 CFR 222.7, ER 1110-2-240 Water Control Management
Authorized flexibility to manipulate water levels to benefit fish and wildlife.	Fish and Wildlife Coordination Act (16 USC 661)
Legal requirement for the agency to determine whether the action will have significant environmental impact and if so requires the preparation of an Environmental Impact Statement or a lesser detailed Environmental Assessment	1969 National Environmental Policy Act
Addresses the provision of recreational opportunities.	1965 Federal Water Project Recreation Act
Prevents drawdown to provide flood control storage.	1934 'Anti-Drawdown Law'
Regulation of navigation pools.	Master Regulation Manual for Mississippi River Nine Foot Channel

end of the pool, where the reduction in water surface elevation would be less than half of that at the dam. Long-term resource monitoring had been conducted on Pool 8 for more than 12 years, and there were many agency personnel available to conduct additional monitoring. The public was supportive of Pool 8 for the first demonstration drawdown. Pools 5 and 6 were selected for subsequent drawdowns.

Development of a pool drawdown plan

Drawdown alternatives. Parameters considered in the development of alternatives included desired drawdown depth and duration, a range of river discharges, and ability to mitigate impacts on commercial and recreational boating. For Pool 8, three depths of drawdown under four levels of river discharge were evaluated for three durations of drawdown (Table IV). In subsequent planning efforts (i.e. Pools 5 and 6), fewer scenarios were considered when developing drawdown alternatives.

Based on previous studies (U. S. Army Corps of Engineers, 1996), the WLMTF concluded drawdown duration should include as much of the growing season as practical for promoting growth of emergent vegetation, eventually defined as about 90 days. Since the falling hydrograph typically occurs in late May to early June and numerous centrarchid species are spawning through early June, June 15 was selected as the initiation date to coincide with acceptable physical and biological conditions for drawdown implementation. In addition to the start date, previous work (K. P. Kenow, unpublished) documented substantial benefits provided by follow-up drawdown during the subsequent growing season, so a second season drawdown was considered in alternative development.

Mitigating circumstances were considered regarding public concerns about potential impacts of drawdown on recreational boat access and barge access to commercial terminals. In Pools 6 and 8, limits were set to the extent of drawdown at the control points to minimize these impacts. When developing alternatives for Pool 5, recreational access dredging was incorporated to mitigate the impacts of drawdown on recreational boat access

Evaluation of alternatives. Hydrology, sediment transport, pool ecology, channel maintenance, commercial navigation,

Table IV. Drawdown alternatives evaluated when planning pool-wide seasonal drawdowns of Navigation Pools 5, 6, and 8, Upper Mississippi River

Navigation Pool	Depth of drawdown (m)	Flow conditions (m^3s^{-1})	Restrictions	Duration of drawdown
Pool 5	0.46, 0.61, 0.77	850	Drawdown limit at the primary control point (Alma, WI)	15 June – 30 September (growing season) Two consecutive growing seasons
Pool 6	0.15, 0.3	425, 850	0.15-m drawdown limit and no drawdown at the primary control point (Winona, MN)	15 June – 15 September (growing season)
Pool 8	0.3–0.9 @ 0.15-m intervals	280; 623; 1,150; 2,138	Drawdown limit at the primary control point (La Crosse, WI)	15 June – 30 September (growing season) Two consecutive growing seasons

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commercial facilities, and recreation (public boat ramps, commercial recreational facilities, recreational beaches, recreational boating, and submerged hazards) were considered in the evaluation of drawdown alternatives outlined in Table IV. Water surface profiles under the various drawdown alternatives were evaluated using a one-dimensional steady state gradually varied flow model (HEC-2; U. S. Army Corps of Engineers, 1991). Output from the model provided water surface profiles during drawdown at specific river discharge levels, from which attenuation of the drawdown impact upstream of the dam was determined at various discharge levels. This exercise provided insight into the range of river discharge that would be necessary to maintain minimum elevation at the control point under a given prescribed depth of drawdown at the dam. For example, it was determined that to maintain a minimum elevation at the control point during a 0.3-m drawdown at Lock and Dam 8, river discharge would need to be between $481\,m^3s^{-1}$ and $2138\,m^3s^{-1}$.

Hydrologic records were examined to determine the likelihood of implementing an ecologically effective drawdown that would promote desired vegetation response and could be maintained under each drawdown alternative. Criteria for an ecologically effective drawdown were established as (i) drawdown during the 15 June to 30 September growing season, (ii) occurrence of less than one week of reflooding per flooding event, and (iii) occurrence of less than two reflooding events during the growing season. Historic river discharge records (over a 37- to 42-year period) were examined to determine the proportion of years a given drawdown alternative might have been achieved. This information was used as a proxy for establishing the likelihood of success, in any given year, of the alternative depths of drawdown under consideration.

The area of pool substrate exposed under the drawdown alternatives was estimated where bathymetry data were available. This provided a means of assessing the potential for meeting ecological objectives for pool-scale drawdowns which include (i) increasing the extent of annual emergent, perennial emergent, and submersed aquatic vegetation, and (ii) consolidating sediments and reducing sediment resuspension following return to routine pool regulation. In addition, maps were prepared indicating the areas that would be expected to be exposed under each alternative. The effects of drawdown on system sediment assimilation and management, water quality, growth of aquatic vegetation, macroinvertebrates, mussels, fish, amphibians, birds, mammals, and species of concern were also considered on both short-term (during drawdown) and long-term scales.

Routine dredging is required to maintain the 2.7-m channel system and the practicality of navigation channel maintenance during reduced pool levels was a primary criterion for conducting the drawdowns. An assessment of each drawdown alternative was made to determine dredging requirements prior to and during the drawdown to minimize impacts on navigation, based on recent hydrographic surveys. Hydraulic dredging costs were used to estimate costs of both the routine and additional dredging required to accommodate the drawdown. Additional channel maintenance considerations included the availability of dredge placement sites, unobstructed access to the lock chamber, and access to commercial loading and fleeting facilities.

Information about boating access sites, beaches, popular backwater areas, and wing dams (submerged hazard) were used to evaluate potential disruptions of recreational activities. Potential issues with use of public, private, and commercial boating access sites were evaluated and recreation access dredging needs were estimated.

Plan selection. Identification of a preferred pool drawdown plan was a collaborative effort of the WLMTF, the River Resources Forum, and the CEMVP. The selection was based on maximizing ecological benefits while minimizing adverse biological effects, as well as adverse effects on commercial and recreational interests, and to minimize additional channel maintenance requirements. Fiscal considerations and the probability of the occurrence of optimum river discharges for the target drawdown were also considered. A cost–benefit analysis was applied to evaluate ecological benefits in terms of the incremental cost of dredging associated with area of substrate exposed with drawdown.

Both the 0.46-m and 0.61-m drawdowns were under final consideration for Pool 8, but in opting for a cautious approach to minimize the potential for unexpected adverse effects, the 0.46-m drawdown was selected. In the case of Pool 5, the preferred plan was for a 0.61-m drawdown; however, funding could not be secured to accommodate a 0.61-m drawdown and instead the 0.46-m drawdown option was selected for implementation in 2005 because it could be accomplished with available funding. The recommended drawdown of Pool 6 was 0.3 m with a minimum drawdown of 0.15 m at the control point in Winona, MN.

Process for modifying reservoir operating plans

To conduct a pool-scale drawdown, authorization is required from the USACE Mississippi Valley Division to deviate from the approved reservoir regulation plan. The process followed to change reservoir operation for drawdowns necessitated:

(1) preparation of a USACE planning document following requirements of the 1969 National Environmental Policy Act,
(2) preparation of a request to the USACE Mississippi Valley Division to deviate from the approved reservoir regulation plan,

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(3) a Finding of No Significant Impact by the District Engineer, and
(4) USACE Mississippi Valley Division approval of the deviation request.

The purpose of the USACE planning document/Environmental Assessment was to evaluate the feasibility of conducting a drawdown of a given UMR pool and determine if the action would have a significant environmental impact. Information generated for the report was necessary to support the request to deviate from the approved reservoir regulation plan and Finding of No Significant Impact.

Implementation of pool-wide drawdowns

The next phase, planning the logistics of implementation, was detailed in the USACE Planning Document and Environmental Assessment developed for each pool (U. S. Army Corps of Engineers, 1999; U. S. Army Corps of Engineers, 2003; U. S. Army Corps of Engineers, 2005). Participating river management agencies would need to address logistical details pre-drawdown including:

- Channel surveys and advanced dredging as soon as feasible in the spring to accommodate the drawdown.
- Consideration to ensure sufficient funds were available to conduct advanced dredging.
- Provisions in place for recreational access dredging. Federal and state funding mechanisms were identified and secured for limited recreational access dredging in areas with high public use.
- Approval to operate outside the approved water level operating band from the USACE Mississippi Valley Division.
- Partner agencies expertise and resources for monitoring to document changes resulting from drawdowns.

Specific criteria for initiating each drawdown were established including favorable river discharge forecast and acceptable navigation channel conditions. Drawdowns were achieved at a prescribed rate of 6.1 cm per day. Once achieved, the target drawdown elevation was maintained as long as river discharge allowed and safe navigation channel conditions existed. River regulators were requested to minimize fluctuation around the drawdown target elevation to the extent practical. Drawdowns were scheduled to end on or about 15 September and pools allowed to rise at a rate of about 3 cm per day until reaching normal pool levels.

Monitoring. Partner agencies collected information on water and sediment, recreational use, cultural resources, and biological response (Table V). The CEMVP provided expertise and resources for hydrodynamics, hydrographic surveys, and sediment transport. This information was used to manage channel depths during the drawdown and to assess the residual effects of overdraft dredging on the actual cost of main channel dredging during the drawdown. The Upper Mississippi River Restoration-Long Term Resource Monitoring Program and states provided routine sampling to monitor water quality, fisheries, and vegetation. The U.S. Geological Survey, U.S. Fish and Wildlife Service, CEMVP, and states monitored native mussels. The U.S. Fish and Wildlife Service documented relative abundance of reptiles and amphibians, waterbird use, and outbreaks of avian botulism. The U.S. Geological Survey was involved in documenting vegetation response to drawdowns and characterizing the seedbank composition of Pools 5 and 8. Recreational boating was monitored by the MN/WI Boundary Area Commission. Photo stations were established at specific locations and photos taken regularly to document vegetation response.

Public information campaign. The WLMTF and associated agencies provided information about the drawdown to the public to enhance their understanding of pool-wide drawdown objectives and what to anticipate. Specific details were provided on timing of the drawdown, where impacts would be apparent, and where expected habitat changes could be observed. The information was provided through public meetings, presentations to local civic and conservation groups, a dedicated website, a toll-free information line, information signs at boat landings and at associated Lock and Dams, news media releases, and newsletters. The communication process was fluid and allowed managers to respond to public information needs and problems in a timely manner, which was crucial to gaining the respect and trust of the public. The WLMTF considered this public information campaign to be a critical component of the drawdowns. If the public did not understand and support drawdowns as a management tool, then the chances of garnering support for future drawdowns would decrease despite previous successes.

Completion of pool-wide drawdowns. Pool-wide drawdowns were completed on Pools 5, 6, and 8. River flow rates were variable throughout the drawdown periods on each pool and drawdown generally was maintained as long as river discharge remained within prescribed flow constraints. The actual amount and distribution of exposed substrate varied with river discharge and by pool.

The Pool 8 demonstration drawdown was initially scheduled for the summer of 2000; however, it was postponed due to projections of summer river discharges deemed too low for drawdown implementation. A drawdown of Pool 8 (0.46 m) was then scheduled for 2001 from 30 June through 15 September. High spring river discharge levels delayed initiation of the drawdown which reached target levels by 06 July. During the period of maximum drawdown, an estimated 791 ha of substrate were exposed. A drawdown of

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Table V. Monitoring components associated with pool-wide drawdowns of Upper Mississippi River Navigation Pools 5, 6, and 8

Category	Component	Description	Agencies responsible
Water and sediment	Hydrology	Mississippi River and tributary discharge monitored daily	CEMVP
	Hydrodynamics	Water surface elevations, velocity, and discharge obtained along established transects and channel training structures	CEMVP
	Hydrographic surveys	Surveys of main channel and mouths of tributaries conducted pre- and post-drawdown	CEMVP
	Sediment transport	Bed load sampling, suspended sediment, and grain size distribution determined along main channel transects	CEMVP
	Water quality	Bed load sampling, suspended sediment, and grain size distribution determined along main channel transects	WDNR/Long-Term Resource Monitoring Program (LTRMP)
River use	Commercial navigation	Incidences of groundings and other navigation incidents documented; pool transit time	USCG
	Recreational	Boating study via aerial survey and biennial recreational boating study	MN/WI Boundary Area Commission, MDNR, WDNR, CEMVP
Cultural resources		Condition of archaeological and historic sites monitored	CEMVP
Biological	Mussels	Population estimates, mortality, movement, and behavior	USGS/MDNR/WDNR/CEMVP
	Fish	Documentation of fish stranding and fish kills	WDNR/MDNR/LTRMP
	Reptiles and amphibians	Document relative abundance of frogs and toads during breeding season	USFWS
	Birds	Migratory bird use documented during breeding and migration seasons using standardized monitoring techniques	USFWS
	Avian botulism	Intensified effort to monitor for avian botulism outbreaks	USFWS
Vegetation	Photo stations	Established at specific locations and photos taken on a regular basis to document vegetation response	MDNR, WDNR, USFWS
	Seedbank	Determine size and species composition of seedbank present in areas expected to be exposed with drawdown	USGS
	Response on exposed substrates	Assess composition and productivity of moist soil, emergent perennial, and rooted floating aquatic vegetation	USGS
	Submersed aquatic	Assess distribution and biomass of submersed aquatic vegetation	USGS
	Plant community shifts	Assess vegetation response to the drawdown using land cover data generated from high-resolution aerial photography	USGS
Other	Weather	Weather related information collected from existing sources	NOAA
	Structural	Periodic inspections of lock and dams	CEMVP

Pool 8 was repeated in 2002 and maintained near target levels for 75 days (2 July through 15 September).

A 0.46-m drawdown of Pool 5 was conducted from 13 June through 15 September 2005. About 404 ha of substrate were exposed at peak drawdown. However, low discharge restricted the level of drawdown during August and September. An attempt was made to repeat the drawdown in 2006 but was discontinued shortly after reaching the target level because of low and declining river discharge.

A minor drawdown (0.3 m) was scheduled for Pool 6 in 2003, 2004, 2008, and 2009, but river discharge levels were not conducive for a drawdown during those years. A drawdown of Pool 6 was eventually initiated on 18 June 2010 and maintained through 26 August, exposing about 54 ha of substrates. The pool was gradually raised to normal level by 03 September.

While commercial tow boat pilots described pools under drawdown as more difficult to navigate during the drawdown, reports of barge grounding or other issues were minimal or were unrelated to the drawdown (Machajewski 2014). Surveys during the Pool 5 and 8 drawdowns indicated no reduction in the level of recreational boating activity. An extensive effort was made to minimize recreational boating impacts resulting from the Pool 5 drawdown, including formation of a Citizens' Advisory Committee to identify potential problem areas and dredging to provide 'reasonable' recreational access. In some cases, simply moving docks or adjusting channel markers resolved potential issues.

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Abiotic and biotic responses associated with the Pools 5, 6, and 8 drawdowns have been documented in a number of published (Cavanaugh *et al.,* 2006; Custer *et al.,* 2007; Kenow and Lyon, 2009) and unpublished reports (e.g. Kenow *et al.,* 2007; U. S. Army Corps of Engineers, 2007), but a thorough synthesis is beyond the scope of this paper. Preliminary assessments indicated that drawdowns enhanced deep and shallow marsh perennial, rooted floating aquatic, and shallow marsh annual plant communities; had positive effects on fish spawning and nursery areas; improved forage production and availability for migrating waterfowl and shorebirds; and had no measureable adverse effects on fish populations, water quality, or contaminant bioavailability.

Costs incurred to implement drawdowns. Primary costs involved in implementing the drawdowns were supplemental dredging of the main channel and recreational access dredging. While routine dredging is normally required to ensure sufficient depth of the main channel to facilitate commercial navigation, additional dredging was required prior to the drawdowns of Pools 5 and 8 to accommodate the lower pool levels. In each case, supplemental dredging reduced routine dredging needs (and costs) in years subsequent to the drawdown. However, because of the large amount of initial supplemental dredging, the average annual amount of material dredged over a 5-year period (including the year of drawdown) was greater than the annual rate during the pre-drawdown period.

PERSPECTIVES AND DISCUSSION

Several guiding principles emerged from our experiences with pool-wide drawdowns including the need for flexibility in the planning process, public involvement, recreational access dredging, and adaptive management. Incorporating flexibility into the planning process when scheduling and implementing drawdowns was critical. Under the criterion to conduct drawdowns without interfering with commercial navigation, river discharge dictated the depth, timing, and duration of each drawdown. As such, flexibility becomes the foundation of drawdown implementation. For example, the Pool 8 drawdown was originally scheduled for 2000 but was postponed due to low discharge. The initiation of the drawdown was delayed in 2001 due to unacceptably high river discharge. During summer 2002, the discharge fell within prescribed limits for drawdown nearly the entire summer. In order to cope with unpredictable weather patterns and river conditions, natural resource managers, river recreational users, and commercial navigation users need to accept a tentative drawdown schedule. This issue can be problematic because stakeholders desire specifics of starting and ending dates, drawdown duration, and how low water levels will be held. A solution is to provide the public with guidelines for implementation and then let them know the dynamics of the river will dictate whether or not the drawdown will be implemented as planned. This will create confusion, so continual reinforcement of this information is necessary.

Public involvement became one of the most significant issues, both in terms of time commitment and effort expended in establishing the most effective methods to facilitate information exchange. The comprehensive effort and commitment of both river managers and the public became the cornerstone that allowed these drawdown projects to be successfully implemented. The information flow to the public should begin at least 2 years before any drawdown will be potentially implemented.

Another important issue for conducting drawdowns was dredging to maintain recreational access. Each pool drawdown utilized different funding sources or programs to address recreational access dredging needs. The WLMTF ability to implement drawdowns would have been severely compromised had dredging not been part of the pre-drawdown strategy.

The WLMTF recognized the importance of an adaptive management strategy to learn from future drawdowns and the topic was also the subject of a USACE Navigation and Ecosystem Sustainability Program Science Panel Report (Johnson *et al.,* 2010). There remain numerous questions that, if answered, could improve the effectiveness of drawdowns. Future planning should include opportunities to evaluate these and other questions:

- How long do the benefits of drawdowns persist and at what frequency do they need to be implemented?
- What is the pool-specific optimum depth of drawdowns?
- What is the most favorable timing of drawdown initiation and termination for establishment of perennial emergent vegetation?

Next steps

River managers and the public were encouraged by the initial success of pool-wide drawdowns as a tool to improve ecological conditions on the UMR. The next steps for this effort have three major components. First, resource managers are encouraged to seek opportunities to assess the long-term restoration implications of drawdowns. Information on the impacts of drawdowns on vegetation, mussels, fish, wildlife, and other biota over the long-term are critical to understanding the effectiveness of this tool. Second, planning could assess additional large-scale drawdowns and examine the feasibility of conducting minor (i.e. <0.3 m) drawdowns where little to no additional dredging would be required. Finally, this restoration tool could beneficially

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become a routine practice of pool operation in order to create conditions that provide ecological benefits alongside authorities to manage the channel for commercial navigation.

The WLMTF, with strong support from the CEMVP, will continue to analyze these initial drawdown projects as well as implement future drawdowns to determine their significance for habitat restoration. Eventual outcomes may lead to changes in operation of the navigation pools and general drawdown strategies for each pool to promote and maintain the ecological health of UMR pools.

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REFERENCES

Bhattacharjee J, Taylor JP Jr., Smith LM. 2006. Controlled flooding and staged drawdown for restoration of native cottonwoods in the Middle Rio Grande Valley, New Mexico, USA. *Wetlands* **26**: 691–702.

Cavanaugh JC, Richardson WB, Strauss EA, Bartsch LA. 2006. Nitrogen dynamics in sediment during water level manipulation on the Upper Mississippi River. *River Research and Applications* **22**: 651–666.

Custer TW, Dummer PM, Custer CM, Warburton D, Melancon MJ, Hoffman DJ, Matson CW, Bickham JW. 2007. Water level management and contaminant exposure to tree swallows nesting on the Upper Mississippi River. *Environmental Monitoring and Assessment* **133**: 335–345.

Delong MD. 2010. Food webs and the Upper Mississippi River: contributions to our understanding of ecosystem function in large rivers. *Hydrobiologia* **640**: 89–101.

Fischer JR, Claflin TO. 1995. Declines in aquatic vegetation in Navigation Pool No. 8, Upper Mississippi River between 1975 and 1991. *Regulated Rivers: Research and Management* **11**: 157–165.

Fredrickson LH, Taylor TS. 1982. Management of seasonally flooded impoundments for wildlife. U. S. Department of the Interior, Fish and Wildlife Service Resource Publication 148. Washington, D.C.

Fremling CR. 2005. Immortal River. *The Upper Mississippi in Ancient and Modern Times*. University of Wisconsin Press: Madison, Wisconsin; 429.

Fremling CR, Claflin TO. 1984. Ecological history of the Upper Mississippi River. In Contaminants in the Upper Mississippi River: Proceedings of the 15th annual meeting of the Mississippi River Research Consortium, Wiener JG, Anderson RV, McConville DR (eds). Butterworth Publishers: Stoneham, MA; 5–24.

Garvey JE, Dugger BD, Whiles MR, Adams SR, Flinn MB, Burr BM, Sheehan RJ. 2003. Responses of fishes, waterbirds, invertebrates, vegetation, and water quality to environmental pool management: Mississippi River Pool 25. Final Report to the U.S. Army Corps of Engineers, St. Louis Distict, April 2003; 181 pp. Available at OpenSIUC: http://opensiuc.lib.siu.edu/fiaq_reports/4

Harris SW, Marshall WH. 1963. Ecology of water-level manipulations on a northern marsh. *Ecology* **44**: 331–343.

Johnson BL, Barko JW, Bartell SM, Clevenstine R, Davis M, Galat DL, Lubinski KS, Nestler JM. 2010. An adaptive management approach for summer water level reductions on the Upper Mississippi River System. NESP ENV Blue Report, U.S. Army Corps of Engineers, Rock Island District; 67pp. Available at: http://www2.mvr.usace.army.mil/UMRS/NESP/Documents/Water%20Level%20Management%20Report_Final%2028Oct2010.pdf

Kenow KP, Lyon JE. 2009. Composition of the seed bank in drawdown areas of Navigation Pool 8 of the Upper Mississippi River. *River Research and Applications* **25**: 194–207.

Kenow KP, Rogala JT, Boma PJ. 2007. Evaluation of 2006 vegetation response on areas exposed during the 2005 drawdown of Navigation Pool 5, Upper Mississippi River. NESP ENV Report 5, U.S. Army Corps of Engineers, Rock Island, St. Louis, and St. Paul Districts; 10pp. Available at: http://www2.mvr.usace.army.mil/UMRS/NESP/Documents/Evaluation%20of%202006%20vegetation%20on%20Pool%205%20-%20MH%20edit.pdf

Lubinski K, Gaugush R, Gutreuter S, Owens T, Rogers S, Thiel P, Wlosinski J. 1993. Current Ecological Conditions. In *Proceedings of the Forty-Eighth Annual Meeting of the Upper Mississippi River Conservation Committee*, *Red Wing*, *Minnesota*, *March 10-12, 1992*. Reprint by U. S. Fish and Wildlife Service, Environmental Management Technical Center, Onalaska, Wisconsin, October 1993. EMTC 93-R021; 50-63.

Machajewski P. 2014. Commercial tow operator survey. In *Habitat enhancement using water level management on the Upper Mississippi River*, Nissen RA (ed), Water Level Management Task Force – River Resources Forum; p 77. Available at http://www.mvp.usace.army.mil/Portals/57/docs/Navigation/WLM_summary-May%20_2014.pdf

Peck JH, Smart MM. 1986. An assessment of the aquatic and wetland vegetation of the Upper Mississippi River. *Hydrobiologia* **136**: 57–76.

Ramsar. 2013. The Annotated Ramsar List: United States of Amercia. Available at http://www.ramsar.org/cda/en/ramsar-documents-list-anno-list-usa/main/ramsar/1-31-218%5E15774_4000_0__ [accessed 04 April 2013].

Theiling CH. 1995. Habitat rehabilitation on the Upper Mississippi River. *Regulated Rivers: Research and Management* **11**: 227–238.

Tucker JK, Theiling CH, Janzen FJ, Paukstis GL. 1997. Sensitivity to aerial exposure: Potential of system-wide drawdowns to manage zebra mussels in the Mississippi River. *Regulated Rivers: Research and Management* **13**: 479–487.

U. S. Army Corps of Engineers. 1991. HEC-2 Water Surface Profiles User's Manual. Institute for Water Resources, Hydrologic Engineering Center. Available at: http://www.hec.usace.army.mil/publications/ComputerProgramDocumentation/HEC-2_UsersManual_(CPD-2a).pdf

U. S. Army Corps of Engineers. 1996. Problem Appraisal Report for Water Level Management Upper Mississippi River. Water Level Management Task Force – River Resources Forum.

U. S. Army Corps of Engineers. 1999. Definite Project Report – Environmental Assessment – Pilot Pool Drawdown, Pool 8, Upper Mississippi River Wisconsin and *Minnesota*. Water Level Management Task Force – River Resources Forum.

U. S. Army Corps of Engineers. 2003. Letter Report/Environmental Assessment - Pool 6 Minor Drawdown - Upper Mississippi River. Water Level Management Task Force – River Resources Forum.

U. S. Army Corps of Engineers. 2005. Letter Report and Environmental Assessment - Pool Drawdown - Pool5, Upper Mississippi *River*. Water Level Management Task Force – River Resources Forum.

U. S. Army Corps of Engineers. 2007. Upper Mississippi River Pool 8 Drawdown Results. Water Level Management Task Force.

DOI: 10.1002/rra

Available at: http://www2.mvp.usace.army.mil/docs/122sp422_pool8-report.pdf

Weller MW. 1978. Management of freshwater marshes for wildlife. In Freshwater Wetlands: Ecological Processes and Management Potential, Good RE, Whigham DF, Simpson RL (eds). Academic Press: New York; 267–284.

Wiener JG, Fremling CR, Korschgen CE, Kenow KP, Kirsch EM, Rogers SJ, Yin Y, Sauer JS. 1998. Mississippi River. In Status and Trends of the Nation's Biological Resources, Mac MJ, Opler PA, Puckett Haecker CE, Doran PD (eds). Biological Resources Division, U.S. Geological Survey: Reston, Virginia; 351–384.

Wilcox DB, Stefanik EL, Kelner DE, Cornish MA, Johnson DJ, Hodgins IJ, Zigler SJ, Johnson BL. 2004. Improving fish passage through navigation dams on the Upper Mississippi River System. ENV Report 55, U.S. Army Corps of Engineers, Rock Island, Illinois; 110 pp. +Appendices A-D.

Wlosinski JH, Hill L. 1995. Analysis of water level management on the Upper Mississippi River (1980-1990). *Regulated Rivers: Research and Management* **11**: 239–248.

Wlosinski JH, Rogala JT, Owens TW, Dalrymple KL, Busse D, Strauser CN, Atwood E. 2000. Response of vegetation and fish during an experimental drawdown in three pools, Upper Mississippi River. U.S. Geological Survey, Long Term Resource Monitoring Program Technical Report 2000-T001.

Woltemade CJ. 1997. Water level management opportunities for ecological benefit, Pool 5 Mississippi River. *Journal of the American Water Resources Association* **33**: 443–454.

DOI: 10.1002/rra