The WLM Regional Coordinating Committee

July 2022

Water Level Management Opportunities for Ecosystem Restoration on the Upper Mississippi River and Illinois Waterway: An Update to the NESP Environmental Report 53

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Chapter 1. Introduction

1.1 Purpose of this Report

Many previous studies have been conducted to investigate Water Level Management (WLM) actions on the UMRS[1]. One such study is the "NESP ENV Report 53 on Water Level Management Opportunities" (hereafter "NESP Report 53") published in 2004 by the Rock Island (MVR), St. Paul (MVP), and St. Louis (MVS) Districts (Districts) of the U.S. Army Corps of Engineers (Corps). The report discussed the routine methods for managing water levels within the UMRS from each of the Districts. The report summarized potential effects of drawdowns on commercial navigation, recreation, hydropower, and adjacent landowners. The report also assessed the hydrologic conditions experienced in past years, compared them to those necessary to conduct drawdowns in each pool of the UMRS, and summarized the probability of conducting drawdowns in any given year.

This report has been prepared to update and supplement information presented in NESP Report 53. The goal of this updated report is to provide decision makers with critical and up-to-date information for understanding, prioritizing, and implementing drawdowns in the UMRS as a tool to improve ecosystem conditions. Drawdowns carried out during the growing season ("growing season drawdowns") – a form of WLM – are presently receiving substantial attention as a restoration tool on the UMRS. Federal, state, local, and non-profit agencies and institutions are participating in a number of groups seeking to better understand the opportunities for, and challenges to, modifying UMRS water management to increase summer low-water variability and to positively influence UMRS habitat and wildlife. This report aims to provide updated technical information and is not intended to serve as an evaluation of Corps policy, environmental review, or public engagement.

This report update was conducted under the Planning Assistance to States (PAS) Continuing Authorities Program. The study was authorized by Section 22 of the Water Resources Development Act of 1974 (Public Law 93–251), as amended. The study was cost-shared on a 50 percent Federal and 50 percent non-Federal basis. A project partnership agreement was signed with the Upper Mississippi River Basin Association (UMRBA) on February 20, 2018 and is included in Appendix A. WLM Regional Coordinating Committee (RCC) members consist of a representative from each Corps District, U.S. Fish and Wildlife Service (USFWS), U.S. Geological Survey (USGS), National Weather Service, the five basin states Illinois, Iowa, Missouri, Minnesota, and Wisconsin as well as nonprofit partners The Nature Conservancy (TNC), Audubon, American Rivers, National Wildlife Federation, and Waterways Council.

1.2 Background

1.2.1 Navigation and Ecosystem Sustainability Program (NESP)

The Navigation and Ecosystem Sustainability Program (NESP) is a 50-year program of navigation improvement and ecosystem restoration for the UMRS, which includes the Upper Mississippi River (UMR) and Illinois Waterway (IWW). The goals of the program are to implement large-scale projects to improve efficiency and capacity of the Congressionally declared "nationally significant ecosystem and nationally significant commercial navigation system." NESP was funded from Fiscal Year (FY) 2002 to 2009 and suspended after June 2011 due to a lack of appropriations. NESP funds were allocated in

[1] The UMRS includes the Upper Mississippi River (UMR) and Illinois Waterway (IWW)

Corps' FY 20 workplan, $1.5 million for ecosystem and $3 million for navigation planning. In FY 21, NESP received $5 million to continue preconstruction engineering and design, broken into $2.625 million for navigation projects and $2.375 million for ecosystem projects. In FY 22, NESP received $57.2 million, $39.2 for navigation projects and $18 million for ecosystem projects. Of the $57.2 million, $12.1 million was allocated in the Corps' FY 22 work plan.

Under Section 8004, the ecosystem authorization under NESP allows for "… operation of the Upper Mississippi River (UMR) and Illinois Waterway (IWW) to address cumulative environmental impacts of operation of the system and improve the ecological integrity of the Upper Mississippi River and Illinois River." Ecosystem restoration potential projects include "(D) water level management (including water level drawdown)."

1.2.2 Water Level Management for Ecosystem Restoration

The construction of the UMRS locks and dams (L&D) permanently inundated the river floodplain and altered many of the habitats that historically existed. For those reasons, a systemic look at ecosystem degradation is imperative to build resilience in the system. WLM can be utilized as an ecological restoration tool, and when implemented systemically, it has the potential to restore or maintain ecosystem health and resilience over large spatial scales. WLM[2] or environmental pool management (EPM)[3] is an ecosystem restoration tool with the potential to mitigate degrading influences of prolonged inundation and sedimentation and for improving the quality and quantity of habitat available for fish and wildlife. The tool has been utilized and implemented for 25 years in the UMRS (Table 1.1).

This report provides updates to the information presented in NESP Report 53 and leverages the knowledge and expertise of the personnel and agencies that have been involved in ongoing efforts since the publication of NESP Report 53. The report update focuses on MVP and MVR pools, as MVS pools are actively receiving EPM treatment (for within band operations) when conditions allow.

[2] "Water level management" in this report refers to summer growing season drawdowns. "Drawdown" and "water level reductions" are other terms often utilized by the UMRS partnership.

[3] "Environmental Pool Management" is used in St. Louis District's UMR Pools 24, 25, and 26 and is a water management plan that generally reflects summer growing season drawdowns but occurs within the operating band described in the approved Water Control Manual.

Table 1.1: Pool locations and year of WLM implemented since 1994. Note that in Pools 24, 25, and 26, WLM occurred within the operational band of the dams. Information collected by Dave Busse, St. Louis District.

Year	Pool(s)	Year (continued)	Pool(s) (continued)
1994	24, 25, 26	**2008**	*None*
1995	24, 25, 26	**2009**	24, 25, 26
1996	5*, 24, 25, 26	**2010**	6
1997	5*#, 24, 25, 26	**2011**	24, 25, 26
1998	5#^, 13, 24, 25, 26	**2012**	24, 25, 26
1999	5^, 24, 25, 26	**2013**	26
2000	24, 25, 26	**2014**	26
2001	8, 24, 25, 26	**2015**	*None*
2002	8, 24, 25, 26	**2016**	24, 25, 26
2003	24, 25, 26	**2017**	24, 25, 26
2004	24, 25, 26	**2018**	24, 25, 26
2005	5, 24, 25, 26	**2019**	*None*
2006	5, 24, 25, 26	**2020**	24, 25, 26
2007	24, 25, 26	**2021**	24, 25, 26

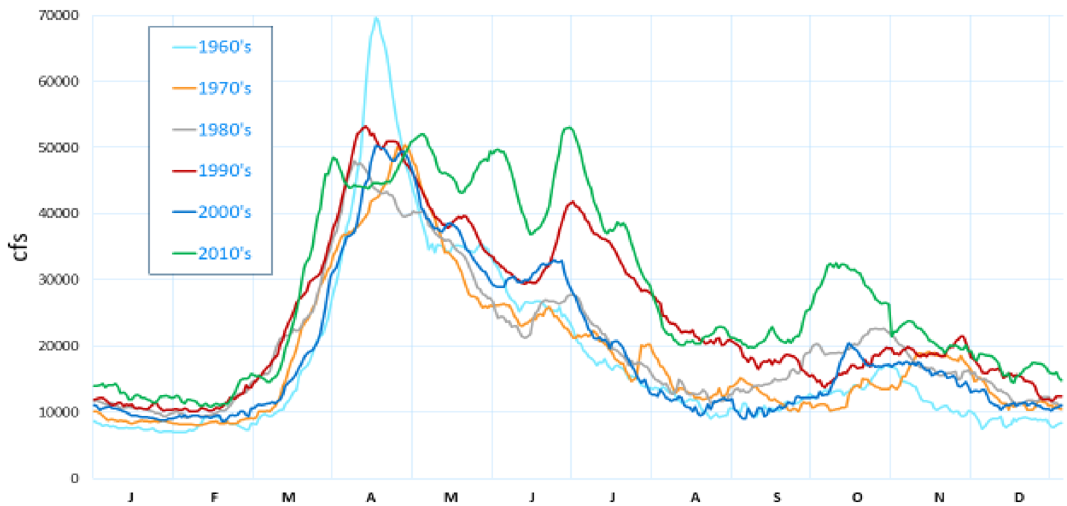
*Small Bay West #Lizzy Paul's Pond ^Peck Lake

1.3 Report Objectives

1.3.1 Document Changes to Relevant Baseline Conditions

Hydrologic and geomorphic conditions on the UMRS have changed in the 17 years since the NESP Report 53 was published. Trend analysis indicates increasing average annual discharges and high discharge conditions that extend well into the growing season (Figure 1.1). This represents a substantial departure from the historic conditions around which the natural ecosystem evolved, including periodic low water levels during the growing season. WLM provides an opportunity to mitigate the impacts of these changed conditions (high discharge and water levels during the growing season) to better mimic the natural historic hydrograph. The probability of successfully conducting a drawdown is an important factor to consider in prioritizing and deciding if and where drawdowns should be carried out. This report updates the chance of success evaluation to consider water levels from 1981 to 2019.

Figure 1.1: Mean daily discharge (in cubic feet per second) by decade (1960-2019) at L&D 3 (near Red Wing, MN). Figure courtesy of Megan Moore, Minnesota DNR.



1.3.2 Recommend Ecological Goals and Objectives

One of the most cited goals of growing season drawdowns is to promote growth of aquatic vegetation. While this is a worthwhile goal and has been a very useful surrogate for considering drawdown benefits, drawdowns have ecological effects beyond improving aquatic vegetation. Ecological effects that have been documented within the UMRS or in other systems during drawdowns include altered organic matter dynamics and increased biomass and diversity of invertebrate populations (Flinn et al. 2005), increased fish abundance (Coulter et al. 2019, Burdis et al. 2020), and increased migratory waterfowl abundance (Larson et al. 2020). Other potential effects that have an experimental or theoretical basis include sediment consolidation (James et al. 2001), nutrient cycling and microbial processes (Cavanaugh et al. 2006), and freshwater mussel growth and recruitment (Rypel et al. 2009, Jones & Neves 2011, Howard & Cuffey 2006). Some adverse ecological effects have been documented including mortality of freshwater mussels in dewatered areas (Newton et al. 2015) and short-term loss of aquatic vegetation in dewatered areas. During the course of this study, the WLM RCC conducted a survey and a workshop to better understand its diverse stakeholder group's vision for WLM activities. The results are summarized in this report. One of the conclusions from the workshop is that despite the available data from previous drawdowns, there are still uncertainties about some drawdown effects. Studies at the scale of full navigation pools can be difficult, expensive, and have limited opportunities as they must occur simultaneously with drawdown events. Implementation of WLM using an adaptive management framework with the inclusion of additional research and monitoring could address some of these uncertainties and could be used in future decision making on when, where, and why the partnership believes it is most appropriate to conduct drawdowns.

1.3.3 Update Costs and Benefits of Drawdowns Based on Current Conditions

NESP Report 53 presented estimated costs and benefits of drawdowns for a subset of nine pools[4] of the UMR within the MVP and MVR Districts. Four different scenarios of drawdowns were considered: 1-, 2-, 3-, and 4-foot reductions of the water surface at each dam. Cost estimates were developed using dredging volumes and dredging costs from previous years. Benefits were presented as a function of the number of acres that were expected to be exposed by conducting a drawdown of a given magnitude on each of the pools.

In the 17 years since NESP Report 53 was published, average annual dredging volumes and costs have increased due to changes in hydrology and geomorphology. River managers desired evaluation of different incremental drawdown scenarios to see if the ratios of costs and benefits may be different for different levels of drawdowns. This report presents updated estimates of costs and acres exposed based on the most up-to-date data available

1.3.4 Develop Ecosystem Benefits Quantification of Drawdowns

Quantifying the ecological outputs of drawdowns is critical to fully understanding the costs and benefits of drawdowns. Previous studies have evaluated drawdown benefits using the number of acres anticipated to be exposed by the drawdown, with the assumption that the land area exposed would likely experience improved aquatic vegetation growth following the drawdown. However, the Corps typically evaluates ecosystem restoration projects in terms of their “net contributions to increases in ecosystem value.” The number of acres exposed does not provide a clear or comparable measure of the increase in ecosystem value that a drawdown provides. Developing a link between the acres exposed and the ecosystem benefits expected would provide context for how much benefit drawdowns provide in comparison to other ecosystem restoration projects like island construction or hydraulic modifications. The Corps used existing information from previous drawdowns and assumptions based on UMRS research to develop a corresponding number of “Habitat Units” that would be provided by drawdowns. When these are combined with the anticipated costs of the drawdowns and the number of acres exposed in each pool under different scenarios, this provides a powerful tool to prioritize drawdowns and compare them to other ecosystem restoration actions being considered.

[4] UMR Pools 5, 7, 8, 9, 11, 13, 16, 18, and 19

Chapter 2. Existing Conditions

The NESP Report 53 included details about the physical setting, water regulation practices, impacts of dam regulation, and descriptions of historical water level management initiatives that had already taken place at that time. WLM initiatives that occurred after the 2004 report include drawdowns in Pool 5 (2005 and 2006) and Pool 6 (2010) and nearly annual EPM actions and monitoring in Pools 24, 25, and 26. A synopsis of the drawdowns in Pools 5 and 6 can be reviewed in the WLM Task Force's 2014 Report: "Habitat Enhancement Using Water Level Management on the Upper Mississippi River" (Nissen 2014). Monitoring results from Pools 24, 25, and 26 can be found in annual reports (USACE 2016, 2017). A selection of the details regarding water control practices that are relevant to understanding the updated information are presented below. The reader is encouraged to refer to the NESP Report 53 for additional details.

In addition to evaluating WLM, the original report also included detailed descriptions and initial evaluations of other potential WLM activities such as pool raises, changing pool control points, modifying the distribution of flow across dams, reducing pool level fluctuation, and inducing winter water level fluctuations. This updated report, however, now focuses on growing season water level drawdowns and does not discuss other WLM actions.

2.1 UMRS Lock and Dam Operation

The purpose of the Lock and Dam (L&D) systems on the UMRS are to maintain a safe and reliable navigation channel, with a minimum depth of 9 feet and suitable widths for navigation traffic. Each pool is operated using one or more 'control point' locations targeted to authorized water surface elevations.

The dams are operated as run-of-the-river structures, meaning they do not actively store and release water (save a minor amount associated with hinge-point control, described below). Rather, the dams are operated to discharge flow equal to that entering the pool from the upstream dam and local tributaries. As river flows increase, the dam gates are opened to pass the increased flow and to maintain the target water surface elevations. As river flows decrease, the dam gates are similarly closed. During periods of high flow (when the dam is no longer needed to maintain a 9-foot channel), the dam gates are lifted clear of the water and taken "out of operation" to avoid backwater effects on adjacent floodplain areas. Under this condition ("open river condition"), the river rises and falls with increasing and decreasing flows.

The dams on the UMRS are operated using three primary methods characterized by the number and location of the control point(s): (1) dam-point control, where a single control point is located just upstream of the dam; (2) hinge-point control, where the primary control point is located at a point upstream along the length of the pool and with a secondary control point located at the dam; and (3) primary–secondary–tertiary control, which utilizes three control points (Table 2.1). The three types of operation are briefly summarized below. Additional information on the regulation of the dams can be found in the individual water control manuals for each project.

Table 2.1: Dam-types organized by pool and Corps District. MVP stands for St. Paul District, MVR for Rock Island District, and MVS for St. Louis District. LSAF is the Lower St. Anthony Falls.

UMR Dam Type	Pool	District	UMR Dam Type	Pool	District	IWW Dam Type	Pool	District
Hinge-Point	2	MVP	Dam-Point	LSAF	MVP	Dam-Point	Brandon Road	MVR
	3	MVP		7	MVP			
	4	MVP		11	MVR		Dresden Island	MVR
	5	MVP						
	5A	MVP		12	MVR		Marseilles	MVR
	6	MVP		13	MVR		Starved Rock	MVR
	8	MVP		14	MVR		Peoria	MVR
	9	MVP		15	MVR		La Grange	MVR
	24	MVS		17	MVR			
	25	MVS		18	MVR			
	Mel Price (26)	MVS		19	MVR			
Primary-Secondary-Tertiary	10	MVP		21	MVR			
	16	MVR		22	MVR			
	20	MVR						

2.1.1 Dam-Point Control

Under dam-point control, a near constant pool elevation is maintained immediately upstream of the dam (the primary, and only, control point). As river flows rise and fall, the pool tilts about the dam (Figure 2.1). The control point is located at the dam itself, and results in stable water levels through the lower portion of the navigation pool for low to moderate flows. This method of operation, however, required greater land acquisition at the time of construction because more land would be inundated than it would have been under hinge-point control operation (described below). Dam-point control is the primary method of operation for the Rock Island Portion of the UMR (with the exception of Pools 16 and 20), Pool 7 in MVP, and the IWW.

2.1.2 Hinge-Point Control

Under hinge-point control, a near constant pool elevation is maintained at the primary control point. This type of control is more complex and requires additional monitoring than does dam point control. The primary control point is located along the length of the pool, near the intersection of the project pool elevation and the pre-project ordinary high water line. As river flows rise and fall, the pool tilts, or "hinges," about this point such that under a rising river (increasing flow) the water surface upstream of the control point rises and the water surface downstream of the control point falls (Figure 2.2). This mode of operation continues until the maximum allowable drawdown at the dam is reached. At this point, the maximum drawdown at the dam (the secondary control point) is maintained for rising flows until the dam is taken out of operation. The primary benefit of this regulation strategy is the need for less land acquisition at the time of project construction. Hinge-point control is the primary method of operation on the UMR in MVP (with the exception of Pools 7 and 10) and MVS.

Figure 2.1: Overview of dam-point control operations

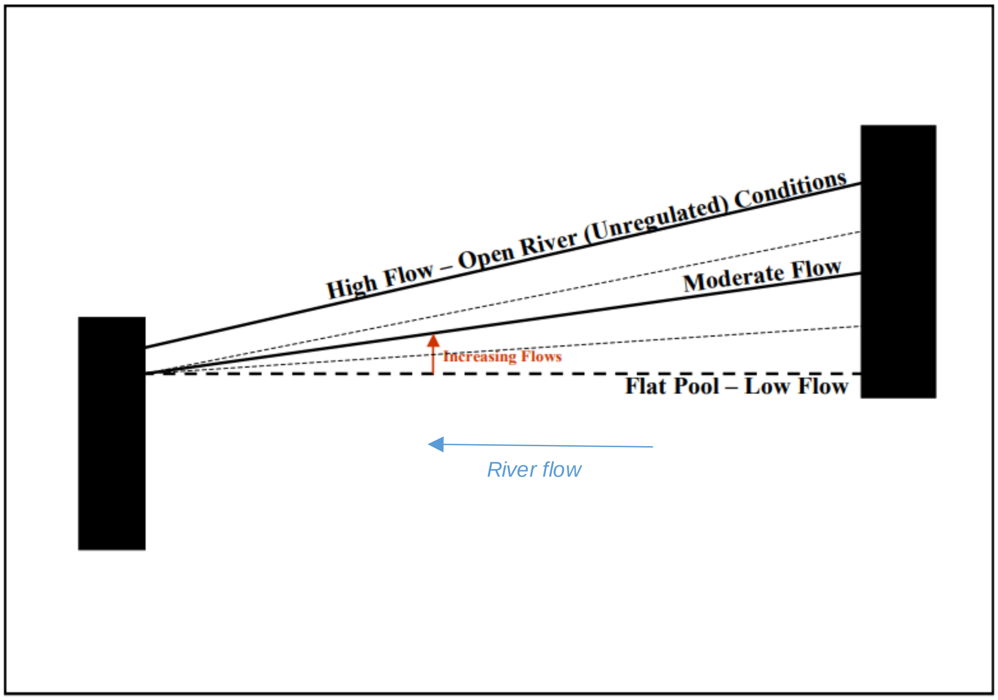
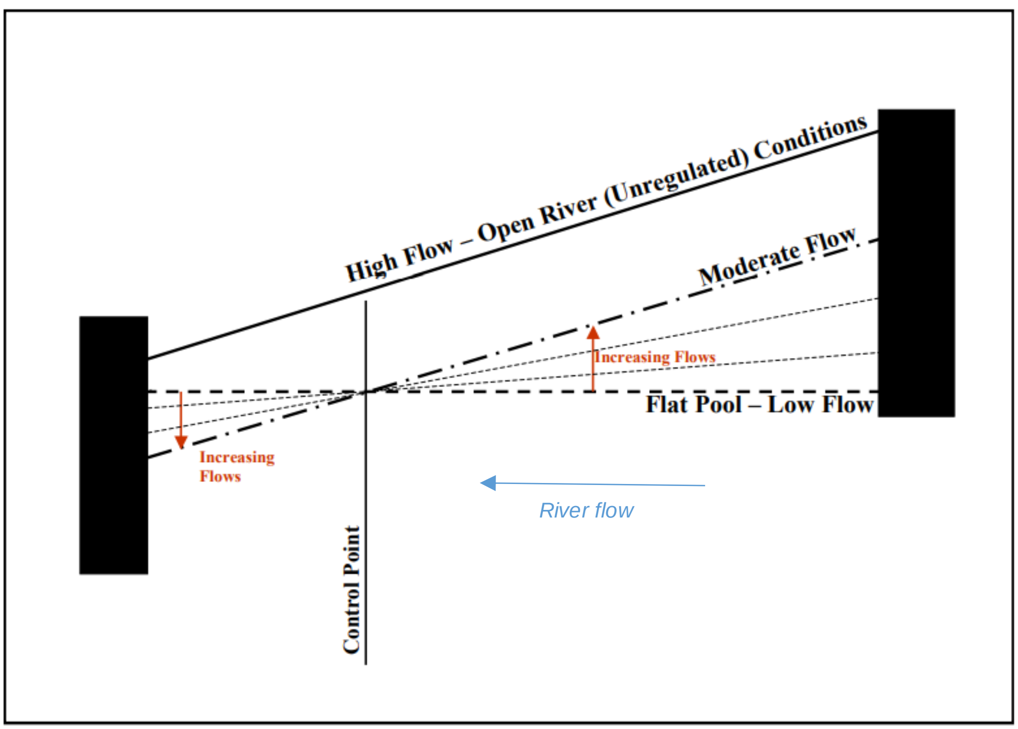


Figure 2.2: Overview of hinge-point control operations



2.1.3 Primary–Secondary–Tertiary Control

Pools 10, 16, and 20 utilize methods of operation involving three control points. For Pools 10 and 16, under low flow conditions, the primary control point is located at the dam. As flows increase, the control point moves upstream to a hinge point (the Secondary Control Point). As the flow continues to rise and the maximum allowable drawdown at the dam is reached, the control point shifts back to the dam (the Tertiary Control Point). This method of operation was chosen to minimize land acquisition in these pools while not exceeding a maximum drawdown at the dam in order to maintain suitable channel dimensions for navigation. Pool 20, under low flow conditions, has its primary control point at Dam 19's tailwater. As flows increase, the control point moves downstream to a hinge point at Gregory Landing (the Secondary Control Point). As the flow continues to rise, and the maximum drawdown at Dam 20 is achieved, the control point shifts further downstream to L&D 20. This method of operation is designed to minimize the backwater impacts of Dam 20 on the hydropower plant at Dam 19 (which pre-dates the 9-foot channel project and Dam 20).

2.2 Upper Mississippi River Regulation Responsibilities

The Corps is responsible for the operation and maintenance of the 9-foot channel projects on the UMRS (Figure 2.3). Water regulation procedures have been developed for each project and are presented in a series of water control manuals (USACE, varying dates of publication). The most recent manuals for each Dam are accessible at: https://water.usace.army.mil). The regulation plans and associated manuals are approved, as per 33 CFR 222.5, by the Division Commander.

2.2.1 St. Paul District

The St. Paul District (MVP) is responsible for operation of thirteen Dams on the UMR, from Upper St. Anthony Falls (USAF) to L&D 10 (Figure 2.3). Daily regulation of Pools 2 through 10 is performed by the MVP's Water Management Section of the Hydraulics & Hydrology Branch. Above Pool 2, the USAF lock is closed to all traffic. USAF, Lower St. Anthony Falls, and L&D 1 are undergoing disposition studies to determine whether the benefits and cost of operation for the District should be continued when the locks are no longer serving their original authorized purposes.

2.2.2 Rock Island District

Upper Mississippi River

The Rock Island District (MVR) is responsible for operation of eleven Dams on the UMR, from L&D 11 to L&D 22 (Figure 2.3). MVR's Water Control Section performs daily regulation of Pools 11-14, 16-18, and 20-22. Dam 15 is regulated locally by the lockmaster due to its interaction with two hydropower dams on Sylvan Slough and due to the (relatively) small pool size that responds quickly to changes made at Dam 14. Dam 19 is a private hydropower facility owned and operated by Ameren. MVR communicates with the hydropower plant daily, providing forecasted releases from Dam 18 and receiving forecasted releases from Dam 19.

Illinois Waterway

MVR is responsible for operation of portions of IWW (Figure 2.3). Of the eight dams on the IWW, only the lower six (Brandon Road to LaGrange) are regulated by the Corps. The Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) is responsible for water control from the Lockport

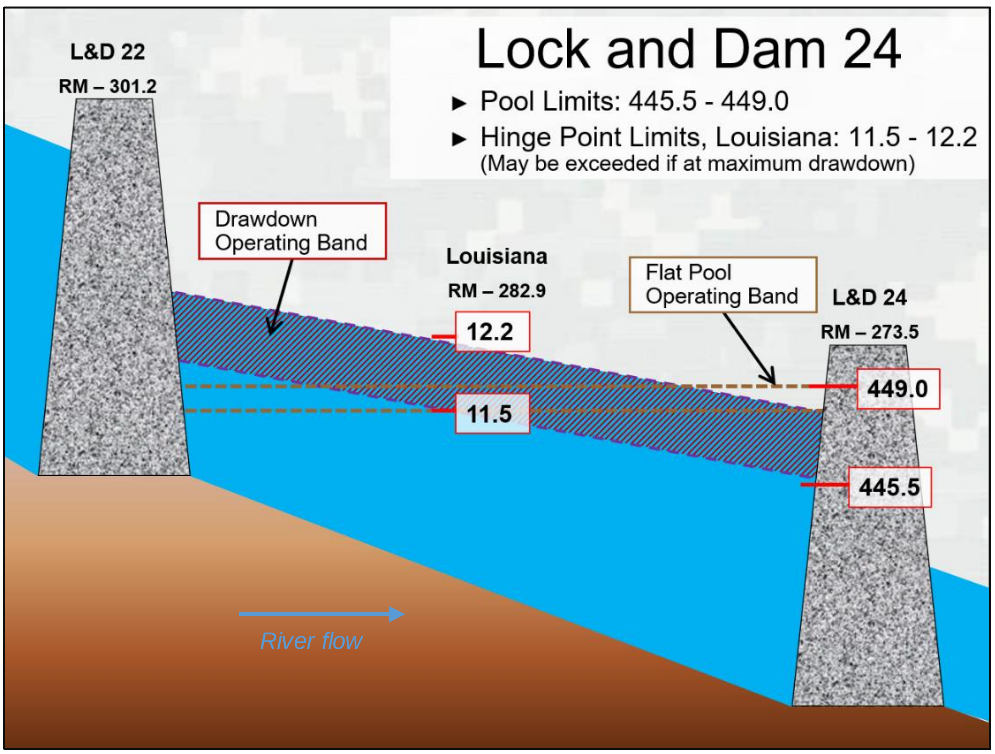
Figure 2.3: The Upper Mississippi River and Illinois Waterway Navigation System

Dam to Lake Michigan. The lower six dams are regulated locally by the individual lockmasters. In 2020, the Chicago District (LRC) took over control of Lockport and T.J. O'Brien L&D. Once the Great Lakes and Mississippi River Interbasin Study and Brandon Road L&D construction is complete, the project will be transferred to LRC.

2.2.3 St. Louis District

The St. Louis District (MVS) is responsible for operation of three Dams on the UMR, from L&D 24 to Mel Price L&D (Figure 2.3) as well as Kaskaskia L&D which regulates the lower 36 miles of the Kaskaskia River. MVS's Water Management Section of the Hydraulics & Hydrology Branch performs daily regulation of the L&Ds. All of the L&Ds in the St. Louis District are hinge point operated, however, the operating range at the hinge points have an upper and lower limit resulting in an operating band at the hinge point gage as well as the L&D pool itself. Figure 2.4 illustrates the typical flexibility available at MVS L&Ds.

Figure 2.4: Example of Typical Hinge-Point Dam Operations within the St. Louis District (MVS)



Chapter 3. Ecological Goals and Objectives

3.1 Summary

In August 2020, UMRBA formed an *ad hoc* group of agency representatives (i.e., state agencies, federal agencies with ecosystem management and authorities) to develop a process for selecting pools based on ecological goals and objectives to conduct WLM. UMRBA hosted a workshop through which participants engaged in structured decision making (SDM). The workshop was supported by a trained facilitator. The Upper Mississippi River Restoration (UMRR) program provided funding to secure a facilitator and the Sustainable Rivers Program provided funding for Corps participation. A summary of the workshop and outcomes are provided below. For a more comprehensive overview of the SDM process and outcomes, refer to the final report: "*Recommendations regarding water level management to achieve ecological goals in the Upper Mississippi and Illinois Rivers*" (Heglund et al. 2022).

The UMRS partnership has a goal of using WLM to improve ecological function and restore the distribution and abundance of fish and wildlife habitat in the UMRS. The UMRBA *ad hoc* group anticipates that the resulting selection process will be used programmatically to implement recurrent WLM.

The UMRBA *ad hoc* group met remotely for a total of 21 hours over six meetings held between March and July 2021 to consider the programmatic implementation of WLM in the UMRS. The facilitator used SDM processes and an adaptive management framework to guide the discussions of the *ad hoc* group.

The UMRBA *ad hoc* group defined the problem to analyze during the workshop as:

> "Currently the WLM RCC lacks clear ecological objectives for selecting candidate pools for water level management, as well as an agreed upon process for selecting and prioritizing pools upon which to focus drawdown efforts. The UMRBA *ad hoc* group wishes to provide a unified recommendation to upper-level Army Corps leadership and others regarding why, where, when, and how to operationalize the implementation of water level management in the Upper Mississippi River System. The primary goals of WLM are ecosystem restoration and enhancement while considering the costs and requirements of commercial navigation, recreational user access, and river dependent businesses."

The following recommendations from the *ad hoc* group are intended for the primary decision makers, who are noted in paratheses 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)

Chapter 4. Costs and Benefits of Growing Season Drawdowns

This chapter presents new and updated information to perform cost-benefit analyses and pool-comparisons of WLM in the UMRS. The process included selecting pools for consideration, estimating dredging quantities required under different drawdown scenarios, estimating general dredging costs by pool, estimating the benefits of drawdowns and the likelihood of achieving them, and costs per unit of ecological gain over time. The estimation processes, methods applied, and the assumptions made are documented in this chapter.

Planning and analyzing drawdowns are complex tasks. The analyses in this report were developed at a broad scale, designed to be applicable across many pools and intended to help resource managers make generalized comparisons between pools. There are many trade-offs that can be made at each local pool level to change outcomes, but which are far too dependent on unique circumstances to analyze in a report across all pools. The trade-offs may require substantial coordination to reach stakeholder agreement or may be synergistic with other projects that happen to be underway. For instance, resource managers might consider accepting a lower number of days of continuous drawdown to consider an event a "success." As another example, costs could be lowered in a certain pool if there is a contemporaneous opportunity to use sand produced from advanced dredging for a habitat restoration project rather than managing the material outside of the floodplain at Corps placement sites. These pool- or event-specific changes are not captured in the technical analyses of costs or benefits in this report, although care was taken to note potential opportunities where appropriate. The assumptions made in the updated calculations in this report were intended to make comparisons across restoration projects and make it simpler to compare drawdown opportunities under routine operations and conditions.

4.1 UMRS Pool Screening

The WLM RCC reevaluated the list of pools selected for evaluation in the NESP Report 53, and worked with the WLMTF and FWIC, to select the following pools to be evaluated in this report update:

St. Paul District (MVP): Pools 2, 3, 5, 5a, 6, 7, 8, 9, and 10

Rock Island District (MVR): Pools 11, 12,13, 16, 18, 19, 21, 22, and Starved Rock (on the Illinois Waterway)

The rationale of expanding the list of pools from the 2004 report is as follows: while some of the factors to implement WLM may not have changed (e.g., presence of industry, stakeholders in the pool affected by drawdown), it is worth exploring whether updated information changed the hydrologic success, dredging required, or acres exposed for 0.5 foot drawdown increments. The rationale for pool selection is further detailed in Appendices B and C.

4.1.1 Selected Drawdown Scenarios

This update includes drawdown scenarios of 0.5 foot increments up to 2 feet (i.e., 0.5, 1, 1.5 and 2 feet). The WLM RCC acknowledges that dredging costs are reduced under the smaller water level reduction scenarios, that the chance of success is higher for small water level reductions, and that MVP has had previous success with 1.5-foot drawdowns. For those reasons, 3- and 4-foot drawdown scenarios were eliminated as they are less feasible to implement. While some additional management likely exists, given the success of existing within-band WLM, the 3 pools in the St. Louis District (MVS) were not included in this evaluation. These pools could be evaluated separately in the future using the framework and tools presented here.

4.1.2 Selected Pools for Evaluation

In general, pools were considered for evaluation unless there was a known reason to exclude it. The rationale for evaluating pools or not evaluating pools in the UMRS was discussed at the river team level: the WLMTF in MVP and the FWIC in MVR. The general reasons to evaluate or screen a pool are outlined below. Any combination of the factors results in the river team decisions (Appendices B and C).

Reasons to include in evaluation:

— Aquatic vegetation is in a degraded state

— Dredging required is on the lower end of the District's annual dredging volume

Reasons to exclude from evaluation:

— Tributary and upstream influences (e.g., Chicagoland for the Illinois Waterway)

— Little floodplain exposed from reduced water levels (e.g., urban areas or leveed areas)

— Heavily-impacted stakeholders (e.g., industry and recreation in urban areas)

— Channel hazards unmitigable by dredging (e.g., Chain of Rocks)

4.2 Costs

The cost of dredging and managing the dredged material are the primary expenses for conducting WLM. Dredging is conducted throughout the UMRS in areas where shoaling and deposition regularly occurs to maintain the 9-foot navigation channel. In the MVP and MVR Districts of the UMRS where drawdowns are being considered, routine dredging practices only remove enough sediment to maintain the Navigation Channel at the water levels prescribed in the current Water Control Manuals. Therefore, additional dredging is required if water levels are reduced beyond the lowest normal levels. The costs of the dredging and dredged material management were estimated to understand the potential differences in costs of performing drawdowns in each pool.

4.2.1 Dredging Quantity Estimation Methods

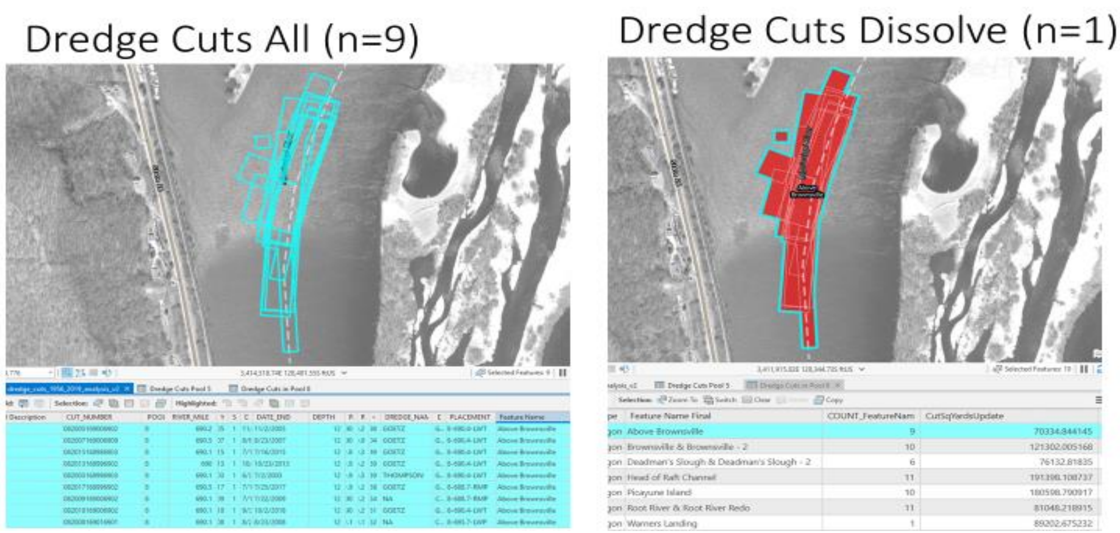
The objective of calculating dredging required for WLM actions is to determine the amount of additional dredging needed for various drawdown scenarios. The primary assumption of this report is that in order to perform a drawdown and maintain a safe and reliable navigation channel, all dredge cuts within a given pool would require additional dredging correlated to the level of drawdown at that location. There may be specific locations or scenarios in which this additional dredging could be reduced. However, it was not possible to evaluate the level of detail for each pool in this report. This report takes the approach of estimating and generalizing dredging needs using a consistent approach across pools to make high-level comparisons.

The most precise method for calculating the amount of dredging required would be using recent survey data and determining dredging requirements for each known dredging location within the river. This process is time-intensive and was not feasible to conduct for every dredging location and scenario across all pools. It is also only precise for the current conditions and would lose value after additional sedimentation and dredging occurs. The team instead investigated estimation methods, and then used data from past drawdowns to calibrate the estimates to known events. Specifically, the team compared the modeling results from Pool 8 and Pool 5 to actual dredging amounts from drawdowns in those pools (2001 and 2005, respectively). The team also compared the modeling estimates from Pool 3 to cut-by-cut analyses that were prepared in 2015 for drawdown planning in that pool. These were precision estimates using actual surveys and detailed analysis of each dredge cut. A drawdown was conducted in Pool 6 in 2010, but no additional dredging was conducted specifically for this drawdown. Therefore, there was no data for calibrating estimates from that drawdown.

The final, calibrated estimation method developed for this report includes three basic steps: (1) compute water surface elevations during drawdown scenarios and compare to normal conditions, (2) find the maximum spatial extent of existing dredge cuts, and (3) multiply the total cut area by the amount of drawdown estimated at that cut. The estimated dredging quantities for individual cuts were then totaled for each pool and scenario.

First, the reduction in water surface elevation was calculated for each dredge cut under each drawdown scenario. The calculation includes computing Low Control Pool drawdown (LCP DD) elevation and subtracting the value from the Low Control Pool (LCP) elevation under routine operation to determine the additional dredge cut depth. LCP is the lowest expected water surface elevation during a navigation season and is used to determine how deep to dredge the navigation channel at each dredge cut. LCP DD is determined using linear interpolation based on the lowest drawdown at the dam for each of the four drawdown scenarios (i.e., 0.5 feet (ft), 1 ft, 1.5 ft, and 2 ft), and the lowest drawdown at the control point. For dam point control, LCP throughout the pool was set equal to the water surface profile for the discharge exceeded 95% of the time in that pool based on the Corps Water Management System (CWMS) simulations.

Figure 4.1: An example of using the ArcGIS Pro "dissolve" tool for the "Above Brownsville" dredge cut area in UMR Pool 8. The individual dredge cuts from 2003 to 2019 were spatially overlayed as multiple events (left image), then were combined into one complex shape (right image).



Next, the spatial extent of each dredge cut was delineated. A "composite" dredge cut surface area was created to represent the maximum areal extent that would require dredging for each routinely dredged location. This was created by combining the surface area of individual dredge cuts within a given river reach from 2003 to 2019 into one complex shape using the "Dissolve" function in ArcGIS (Figure 4.1). This is the time period for which complete geographic information systems (GIS) dredge cut data is available. There is a gap in data from 1999 to 2002 and although it would be possible to create additional data for the years prior to 1999, the team felt that 17 concurrent years (2003-2019) of dredging data was a large enough sample size to complete the analysis. The time period includes representative variation in the magnitude, duration, and timing of high and low flow years, and variation in programmatic factors such as annual O&M budgets, dredge plant availability, placement site capacity, and the duration of the channel maintenance season. The selected period of analysis is representative of contemporary dredging volumes that are generally higher than in the 1980s and 1990s. Additional details on the dredging required estimation methods and associated definitions can be found in Appendix D.

Finally, the area of each composite dredge cut surface area was multiplied by the amount of water surface elevation reduction to result in the volume of additional dredging expected.

4.2.2 Dredging and Material Management Cost Estimate Methods

Costs associated with dredging and dredged material management can vary widely. The material dredged annually from the UMRS Navigation Channel is managed by the Corps according to plans in place for each pool. These plans are developed with consideration of many factors within each pool and vary substantially due to river access, land availability, past management strategies, opportunities for beneficial re-use of material, state permitting requirements, and the amount of dredging typical for that location. These factors may also change over time.

For this report, channel maintenance specialists estimated costs based on personal knowledge of the dredging processes. First, the most likely management strategies for each pool were identified. These included the initial dredging, placement of material, and then secondary material transfer from temporary placement sites to permanent placement sites. Costs for performing each of these steps were estimated using a combination of FY2021 contract mechanical and hydraulic dredging costs, government equipment hydraulic dredging costs, and the most recent unloading contacts for temporary placement sites where applicable. Costs were generalized, rounded to the nearest dollar, and are presented in 2021 dollars. Estimates did not account for mobilization or de-mobilization costs, pre- or post-survey costs, dredging Quality Assurance/Quality Control, contract preparation and administration costs, support labor, or environmental review. Many unknown factors could also substantially impact costs (both positively and negatively) in the future, such as required changes in dredged material management strategies, fuel price adjustments, placement site capacity, and changes in beneficial use at placement sites.

4.2.3 Results and Discussion

Average annual dredging in MVP pools ranges from 32,000 cubic yards (Pool 10) to 124,000 cubic yards (Pool 5) (Table 4.1). Average annual dredging in MVR pools ranges from 17,000 cubic yards (Pool 12) to 79,000 cubic yards (Pool 18) (Table 4.2). WLM for each drawdown scenario 0.5 feet through 2 feet requires additional dredging.

Dredging and management costs ranged from $8 to $25 per cubic yard of material. The cost per cubic yard in MVP ranged from $10 (Pools 5A and 9) to $25 (Pool 10). For MVR, the range of cost per cubic yard is from $8 (Pool 12) to $21 (Starved Rock). Costs were lowest in areas where minimal material management is required after the initial dredging event, and highest where material needs to be transferred between multiple sites or transferred from the dredging location. Costs presented assume that dredging and material management is performed through the Corps' Channel Management Operations and Maintenance program. In locations where material management is more expensive because re-handling is required from temporary to permanent sites (e.g., Pool 3, Pool 5, or Pool 10), these costs could be reduced if a permanent placement site or nearby habitat restoration project was available for placing the material.

Dredging required estimates were also produced in the NESP Report 53 publication (Appendix E). While less is known about the methods used to develop those estimates, the amount and cost of drawdown dredging indicated by the analyses done for this report are substantially higher than those estimated in 2004.

Table 4.1: Average annual dredging (2003-2019), estimated additional dredging required for drawdown scenarios, and estimated costs of drawdown dredging by UMR Pool in MVP[5]

Pool	Average Annual Dredging (CY)	Estimated Management Cost per CY	Additional Drawdown Dredging *Drawdown Scenarios* 0.5	1	1.5	2	Estimated Drawdown Dredging Cost *Drawdown Scenarios* .5	1.0	1.50	2.0
2	95,000	$ 10.00	135,000	207,000	280,000	352,000	$ 1,350,000	$ 2,070,000	$ 2,800,000	$ 3,520,000
3	58,000	$ 25.00	70,000	121,000	172,000	280,000	$ 1,750,000	$ 3,030,000	$ 4,300,000	$ 7,000,000
5	124,000	$ 20.00	188,000	242,000	297,000	352,000	$ 3,760,000	$ 4,840,000	$ 5,940,000	$ 7,040,000
5A	47,000	$ 10.00	38,000	63,000	88,000	113,000	$ 380,000	$ 630,000	$ 880,000	$ 1,130,000
6	46,000	$ 16.00	84,000	118,000	151,000	185,000	$ 1,340,000	$ 1,890,000	$ 2,420,000	$ 2,960,000
7	48,000	$ 16.00	79,000	159,000	238,000	317,000	$ 1,260,000	$ 2,540,000	$ 3,810,000	$ 5,070,000
8	77,000	$ 15.00	125,000	177,000	229,000	349,000	$ 1,880,000	$ 2,660,000	$ 3,440,000	$ 5,240,000
9	66,000	$ 10.00	73,000	75,000	77,000	79,000	$ 730,000	$ 750,000	$ 770,000	$ 790,000
10	32,000	$ 25.00	86,000	127,000	167,000	207,000	$ 2,150,000	$ 3,180,000	$ 4,180,000	$ 5,180,000

[5] Average Annual Dredging was calculated using data from 2003-2019
All values in cubic yards (CY) are rounded to the nearest thousand.
Estimated Management Cost per CY estimated by considering a typical cost to dredge, place, and move material between the placement sites available in each pool. Dredged material management strategies differ by pool
Estimated Drawdown Dredging cost is calculated for each drawdown scenario by: (Additional Drawdown Dredging x Estimated Management Cost per CY)
Estimated Drawdown Dredging cost does not account for any potential future cost savings for reduced dredging in following years, as this reduction is not guaranteed. Acceptable accounting methods have not yet been developed.

Table 4.2: Average annual dredging (2003-2019), estimated additional dredging required for drawdown scenarios, and estimated costs of drawdown dredging by UMRS Pool in MVR.[5]

		Estimated	Additional Drawdown Dredging				Estimated Drawdown Dredging Cost			
	Average Annual	Management	*Drawdown Scenarios*				*Drawdown Scenarios*			
Pool	Dredging (CY)	Cost per CY	0.5	1	1.5	2	.5	1.0	1.50	2.0
11	20,000	20.00	19,000	65,000	115,000	162,000	$ 380,000	$ 1,300,000	$ 2,300,000	$ 3,240,000
12	17,000	8.00	26,000	58,000	89,000	120,000	$ 210,000	$ 460,000	$ 710,000	$ 960,000
13	45,000	10.00	53,000	151,000	247,000	335,000	$ 530,000	$ 1,510,000	$ 2,470,000	$ 3,350,000
16	48,000	10.00	145,000	257,000	337,000	399,000	$ 1,450,000	$ 2,570,000	$ 3,370,000	$ 3,990,000
18	79,000	10.00	39,000	133,000	258,000	379,000	$ 390,000	$ 1,330,000	$ 2,580,000	$ 3,790,000
19	10,000	10.00	-	15,000	34,000	53,000	$ -	$ 150,000	$ 340,000	$ 530,000
21	52,000	10.00	42,000	133,000	260,000	385,000	$ 420,000	$ 1,330,000	$ 2,600,000	$ 3,850,000
22	75,000	10.00	72,000	185,000	313,000	446,000	$ 720,000	$ 1,850,000	$ 3,130,000	$ 4,460,000
Starved Rock	23,000	21.00	30,000	62,000	93,000	124,000	$ 630,000	$ 1,300,000	$ 1,950,000	$ 2,600,000

Two shortcomings of this estimation method should be acknowledged. This method likely overestimates the dredging required in any individual dredge cut, because dredge cuts are not typically uniform and may not require dredging across the entire surface area. On the other hand, the estimation method ignores marginal channel areas or historic dredge cuts that are not routinely dredged but which may require dredging under drawdown conditions. Because the estimates closely matched the observed (Pools 5 and 8) and predicted (Pool 3) dredging quantities from previous drawdowns and cut-by-cut analyses, the described methods produced a reasonable dredging estimate for the pools overall. The analyses presented in this report are intended as a screening-level analysis. If pools are selected for drawdowns, a more detailed analysis would be done.

4.2.4 Analyzing Benefits of Advanced Dredging to 9-Foot Channel O&M

The deeper dredging conducted to accommodate the lower water surface elevations during drawdowns can impact future dredging. The extent of the effects is difficult to quantify and is highly dependent on hydrologic conditions that follow the initial dredging. The increased initial dredging can lead to reduced dredging for several years before the deeper dredge cuts fill back in. However, when an area is dredged deeper, the sediment trap efficiency of that area increases. This means that a greater percentage of the sediment moving in the river is deposited within the cut, rather than transported past it. Events that cause increased sediment transport in the river (e.g., floods or periods of high discharge) may quickly fill in the deeper dredged areas. Furthermore, costs for additional dredging are incurred up-front, while benefits are realized in the future and cannot be reliably predicted. Even if benefits are realized in following years, there is always an *overall* increase in the material dredged from a cut or pool when deeper dredging is conducted due to the increase in sediment trap efficiency that is experienced as dredging depth increases.

The costs presented in this report do not take into account the potential reduction in dredging in the years immediately following a drawdown or the longer-term increase in dredging due to increased sediment trap efficiency. All costs of dredging deeper to accommodate the drawdown scenarios are attributed to the drawdown itself. As there is a possibility of few or no benefits to be realized to channel maintenance and, even if benefits are realized in the form of reduced future channel maintenance, there are not clear methods for measuring these benefits. There are also no known existing Corps policies or fiscal accounting methods to “pay back” entities or other Corps programs for the apportioned share of benefits.

The authors of this report are unaware of any applicable policies or existing programs that have been implemented within the Corps that would be similar to this scenario where the actions for creating ecosystem benefits have uncertain costs, and which have the potential for affecting future costs to operation and maintenance of a navigation system. Future research and coordination could help resource managers better understand opportunities for drawdowns by outlining applicable Corps policies, fiscal responsibilities, potential cost-sharing opportunities, and methods of measuring and accounting for potential benefits.

4.3 Hydrologic Success Rates Analysis

The hydrologic success rate is the probability that flow conditions remain within an acceptable range, for sufficient duration, to achieve the desired benefits of the growing season drawdown. Hydrologic records for each L&D can be used to examine the proportion of years that a given drawdown scenario could have been conducted. Pools can vary significantly in this regard. This is an important consideration, especially given that the costs of implementing a drawdown (dredging) are incurred before a drawdown is implemented.

Additionally, how "success" is defined can influence the outcome because it is somewhat subjective – there is a wide range of drawdown timing and durations that can provide different benefits. The WLM RCC members examined previous definitions, records of past drawdown outcomes, and the scientific literature to identify targets for a successful drawdown for the purpose of this report. The updated definitions are as follows:

> The "optimal" event is at least 90 days of drawdown at the prescribed pool reduction level defined by planning experts within the growing season (May 15-September 15).
>
> The "minimum" criteria for success is maintaining the pool reduction for at least 80% of a 60 day period (i.e., no more than 12 days of inundation in the 60 day drawdown period) during the growing season.

These definitions are not intended to be final but are used in this report for the purpose of evaluating and comparing the likelihood of meaningful drawdowns in pools. Research identifying how different vegetation species respond to various drawdown lengths and clarifying the differences between shorter and longer drawdowns may lead managers to modify these definitions for future projects.

The above definitions of "success" vary from the definition used in NESP Report 53, which used a 60-day continuous drawdown period, occurring between May 1 and August 31, as the success criteria.

In this updated report, daily flow or stage records for each pool were used to determine annual success rates using the definitions provided by the WLM RCC. The period from 1981 to 2019 was chosen for the analysis to reflect the more recent, wetter, period of the historical record. Therefore, differences between success rates reported in NESP Report 53 and those presented herein are due to a change in the defined success criteria as well as differences in the period of record used.

Methods

The hydrologic success rate was determined by completing three basic steps within each pool:

(1) Determine the range of river flows that would allow a drawdown for each pool for different levels of drawdown.

(2) Using daily historical flow data (May 15 - Sept. 15; 1981-2019), determine the frequency of exceedance of the river discharge with respect to the allowable range for a drawdown.

(3) Determine the percentage of time during the growing season that discharge was within the allowable drawdown range.

For each pool, the acceptable flow range for conducting a drawdown was identified based upon the following considerations:

- For all pools, the highest river condition for which a drawdown could be maintained is the point at which open river conditions would begin for a given drawdown depth. At greater discharges, the dam is taken out of operation and the water level will rise with increasing flow.

- The lowest river condition for which a drawdown could be maintained varies by the type of dam management approach in use at each project:
  - Hinge-Point Control: For dams operated using hinge-point control (Pools 2, 3, 5, 5A, 6, 8, and 9), the lowest river condition for which a drawdown (measured at the dam) could be maintained was assumed to be the flow that resulted in a stage 0.5 foot below the target water surface at the mid-pool control point.

  - Dam-Point Control: For dams operated using dam-point control (Pools 7, 11, 13, 18, 19, 21, 22, and Starved Rock), no low flow constraint was identified. This implies that water levels could be reduced over the entire pool length to the level of the drawdown.

  - Primary-Secondary-Tertiary Control: For dams that utilize primary-secondary-tertiary control (Pools 10 and 16), different methods were utilized for each pool due to unique constraints in Pool 16. For Pool 10, the procedures for the hinge-point control dams were used with the secondary control point treated as the hinge point. Within Pool 16, there is extensive rock within the main channel along the upper portion of the pool. As part of the original 9-foot channel project, rock excavation occurred in this reach to provide a minimum 11 feet of depth above the rock at flat pool. For Pool 16, the lowest river condition for which a drawdown could be maintained was selected as the flow condition that produced a water surface at flat pool near the downstream extent of the main channel rock (near River Mile 484).

Historical flow data was obtained from Corps' records from each L&D evaluated (generally available online at www.rivergages.com). A spreadsheet of daily flow records was compared to the flow ranges for each dam that would allow a drawdown. The spreadsheet compared the daily flow records to the success criteria for each year to determine if a drawdown could have been conducted for the specified length of time. Finally, the percentage of historical years in which each pool would have met the identified drawdown criteria was calculated. This percentage of historical years is the number presented in the results tables (4.3 and 4.4).

Results

The results of the hydrologic success rate analyses are shown in Tables 4.3 and 4.4. Results are organized into two separate tables due to the differences in computation procedures that were used for each dam regulation type (i.e., hinge-point vs. dam-point). Figures 4.2 and 4.3 graphically show the average daily success rates for one representative pools of each dam regulation type.

Table 4.3: Estimated rate of hydrologic success for drawdowns in selected pools of dams operated under hinge point and primary-secondary-tertiary control, based on the 1981-2019 period of record. Values are the percentage of the years meeting drawdown criteria.

		0.5' Drawdown		1.0' Drawdown		1.5' Drawdown		2.0' Drawdown	
River	**Pool**	**Optimal**	**Minimum**	**Optimal**	**Minimum**	**Optimal**	**Minimum**	**Optimal**	**Minimum**
UMR	2	49%	85%	41%	85%	31%	74%	15%	54%
	3	28%	59%	5%	28%	0%	21%	0%	3%
	5	92%	97%	80%	95%	72%	85%	64%	85%
	5A	39%	62%	13%	33%	5%	18%	0%	5%
	6	51%	87%	44%	64%	31%	54%	21%	41%
	8	64%	92%	59%	90%	49%	80%	46%	67%
	9	18%	36%	23%	36%	0%	10%	0%	5%
	10	13%	33%	0%	21%	0%	3%	0%	0%
	16	62%	90%	46%	85%	33%	69%	23%	51%

Table 4.4: Estimated rate of hydrologic success for drawdowns in selected pools of dams operated under dam-point control, based on the 1981-2019 period of record. Values are the percentage of the years meeting drawdown criteria.

		0.5' Drawdown		1.0' Drawdown		1.5' Drawdown		2.0' Drawdown	
River	**Pool**	**Optimal**	**Minimum**	**Optimal**	**Minimum**	**Optimal**	**Minimum**	**Optimal**	**Minimum**
UMR	7	92%	100%	77%	97%	64%	92%	51%	87%
	11	92%	100%	92%	100%	90%	97%	90%	97%
	12	67%	87%	56%	87%	44%	80%	44%	77%
	13	90%	97%	90%	97%	87%	95%	77%	95%
	18	62%	92%	59%	90%	56%	90%	49%	82%
	19	100%	100%	100%	100%	100%	100%	100%	100%
	21	38%	74%	38%	74%	33%	69%	31%	64%
	22	46%	85%	41%	82%	38%	74%	38%	74%
IWW	Starved Rock	100%	100%	100%	100%	100%	100%	100%	100%

Figure 4.2: Success rates for 0.5-, 1-, 1.5- and 2-foot drawdowns spanning the summer growing season (May 15-September 15) in UMR Pool 5. Note that because a 0.5-foot drawdown constraint was assumed at the mid-pool control point, the chance of success tends to decrease later in the year when lower flows can violate this constraint. This is consistent across all pools evaluated that are operated by hinge-point control.

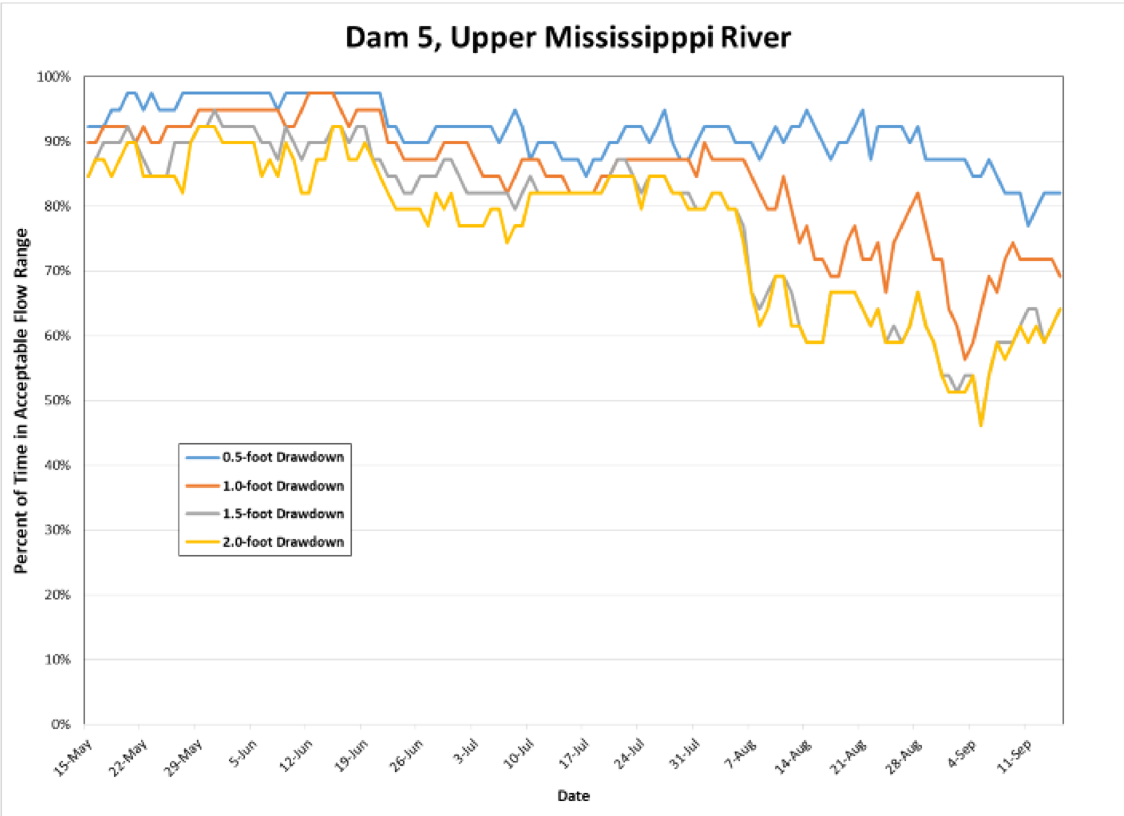
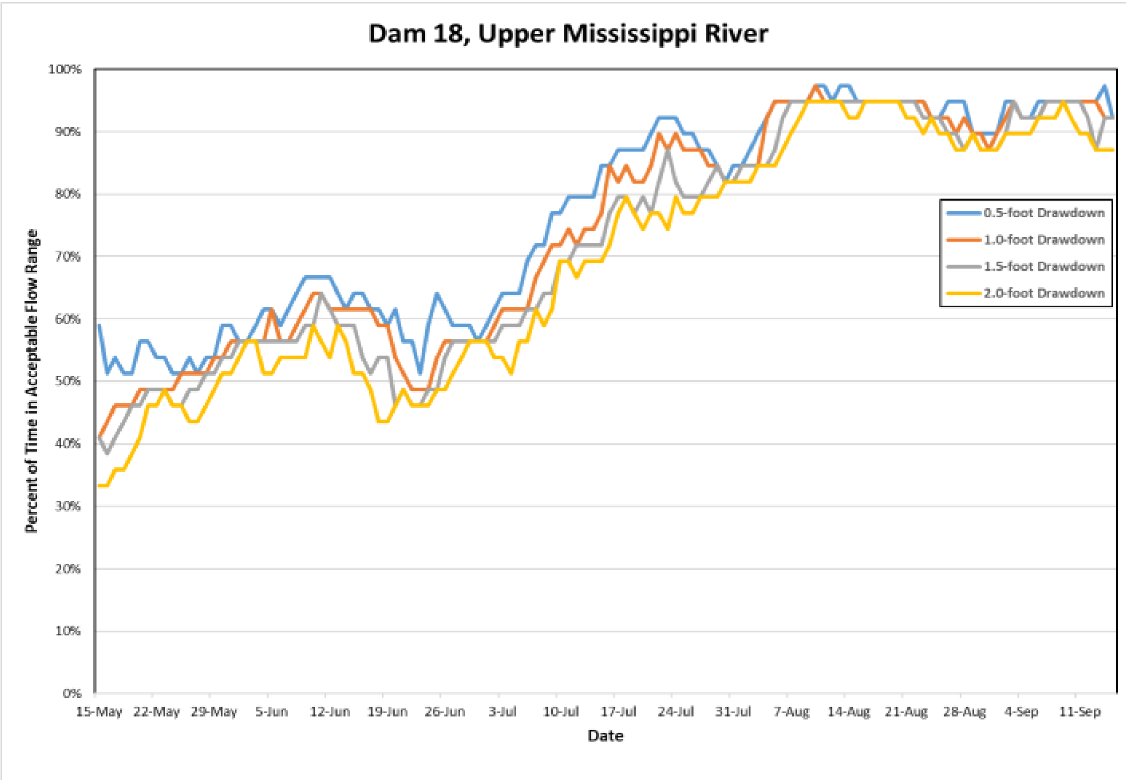


Figure 4.3: Success rates for 0.5-, 1-, 1.5- and 2-foot drawdowns spanning the summer growing season (May 15-September 15) in UMR Pool 18. Note that with no upstream constraint, the chance of success tends to increase later in the year when lower flows are likely. This is consistent across all pools evaluated that are operated by dam-point control.



Discussion

Many pools display a measurable difference in hydrologic success rates between the optimal and minimum criteria. Drawdowns using the minimum hydrologic success criteria have up to a 44% higher chance of success than those using the optimal criteria, with an average of 21% higher chance of success. Pools with low differences between optimal and minimal hydrologic success tended to be those with very high chance of hydrologic success (e.g., Pools 11, 19, Starved Rock). In many cases there are substantial differences in the likelihood of hydrologic success as more days of drawdown are desired. Given this, resource managers should carefully consider the specific ecological goals of a drawdown in a particular pool when defining the target criteria. The criteria determined for this report were based on past experiences and the state of current science. However, drawdowns that do not meet what is here defined as the "minimum" criteria could still provide some ecological benefit to the system. For example, Kenow and Lyons (2009) tested seed bank viability in substrates from Pool 8 of the UMR and found that about 20% of *Sagittaria latifolia* seedlings emerged under the 'moist' treatment within 30 days of the start of the experiment and over 50% emerged within 45 days. These results demonstrate that there is a range of effects that could occur across drawdown lengths, and that a 30-day drawdown may not be considered "successful" based on the definitions used in the hydrologic analyses, there may still be benefits associated with it. This is a major point to consider when assessing the risk posed by the unknown hydrologic conditions that follow advanced dredging to accommodate drawdowns.

Another difference is noticeable between pool operations. Pools operated under dam-point control had an average 38% higher chance of success than pools operated under hinge-point or primary-secondary-tertiary control. This difference was consistent for the minimum and optimum drawdown levels. It is important to recognize this is in large part due to self-imposed artificial constraints that were assumed during the evaluation. For hinge-point pools, a control point constraint was assumed, while no such constraint was assumed for dam-point control pools. The drawdown constraint used at the mid-pool control point of the hinge-point pools is not a hard physical constraint or inherent within the dams themselves. This constraint was successfully used during all past drawdowns in MVP to minimize impacts to river users and minimize dredging requirements in the upper portions of these pools. Readers should be careful when making comparisons between hydrologic success rates presented here for the two types of dams/pools. If direct comparisons are desired, a future screening process should analyze dam point and hinge-point pools with similar constraints assumed.

4.4 Benefits

4.4.1 Acres Exposed

Methods

To estimate the number of acres exposed by drawdowns (of varying magnitudes) in the selected pools, the existing CWMS Hydrologic Engineering Center River Analysis System (HEC-RAS) models and the USGS UMESC Topobathy (i.e., topography and bathymetry) datasets were used. The analysis focused on computing the maximum potential number of acres that could be exposed by a given drawdown depth in each pool:

- For hinge-point control dams, the maximum pool exposure would occur at the lowest flow for which the full drawdown at the dam could be maintained without lowering the water surface more than 0.5 feet below the mid-pool control point.

- For dam-point control dams, the maximum pool exposure would occur during low flow conditions. For this effort the 95% duration growing season flow was used, which means that 95% of the time, river flows are greater than this flow. This corresponds to drought-like or "extreme low flow conditions."

- For Pool 16, due to rock in the main channel, the maximum exposure would occur at the lowest flow for which the full drawdown at the dam could be maintained without the upstream water surface elevation falling below flat pool at the downstream end of the main channel rock.

For the identified flow conditions, the geo-referenced HEC-RAS models were used to generate water surface profiles for the base condition (no drawdown) and each drawdown scenario (i.e., drawdown depth). Each of the water surface profiles were then intersected with the Topobathy elevation dataset in RAS Mapper to generate inundation extents. The inundation extents were exported as a shapefile into ArcGIS where they were clipped by pool and retained for potential future mapping. The estimates of acres exposed by the drawdown alternatives were computed by comparing the inundation extent between the base condition (no drawdown) and each drawdown scenario.

As noted, the estimated acres exposed represent the maximum potential exposure that would occur under optimal (from an exposure standpoint) flow conditions. The expected number of acres exposed could be estimated using the computed maximum potential exposure, the flow at which the dam goes out of operation, and flow-duration information for each pool.

Results

The results of the acres exposed analyses are shown in Tables 4.5 and 4.6. Due to the above differences in computation procedures, results are divided by the type of dam regulation (i.e., hinge-point vs. dam-point).

Table 4.5: Estimated acres exposed by alternative drawdowns for dams in selected pools of dams operated under hinge point and primary-secondary-tertiary control, based on the 1981-2019 period of record. Values are the maximum potential exposure under optimal flow conditions.

		0.5' Drawdown	1.0' Drawdown	1.5' Drawdown	2.0' Drawdown
River	**Pool**	**Acres**	**Acres**	**Acres**	**Acres**
UMR	2	1,014	1,167	1,867	1,976
	3	280	351	510	673
	5	382	606	827	1,204
	5A	399	981	1,408	2,328
	6	411	477	1,003	1,079
	8	968	1,538	2,082	2,740
	9	1,847	1,872	2,726	3,107
	10	1,244	1,607	2,015	2,499
	16	316	867	1,202	1,454

Table 4.6: Estimated acres exposed by alternative drawdowns for dams in selected pools of dams operated under dam-point control, based on the 1981-2019 period of record. Values are the maximum potential exposure under optimal flow conditions.

		0.5' Drawdown	1.0' Drawdown	1.5' Drawdown	2.0' Drawdown
River	Pool	**Acres**	**Acres**	**Acres**	**Acres**
UMR	7	64	1,124	1,678	2,110
	11	679	1,507	2,648	3,461
	12	679	1,241	1,632	1,992
	13	812	1,627	2,593	3,623
	18	508	978	1,420	2,153
	19	1,467	2,438	3,354	4,576
	21	188	366	520	679
	22	66	145	219	295
IWW	Starved Rock	208	395	584	735

Discussion

The results obtained from this exercise are reasonably close to those observed under previous drawdown events. During the previous drawdowns in Pools 5, 6, and 8, aerial imagery was collected when drawdown conditions were achieved and compared to aerial imagery collected under normal water levels to determine the actual acres exposed (Nissen 2014). In Pool 8, aerial imagery collected on July 21, 2001 showed 1,954 acres exposed during a 1.5-foot drawdown. The current analysis estimates that 2,082 acres would be exposed. In Pool 5, aerial imagery collected on July 15, 2005 showed 999 acres exposed during a 1.5-foot drawdown. The current analysis estimates that 827 acres would be exposed. In Pool 6, aerial imagery collected on July 27, 2010 showed 133 acres exposed during a 1-foot drawdown. The current analysis estimates that 477 acres would be exposed, which is more than 3.5 times the number of acres exposed during the aerial photography. The estimates in Pools 5 and 8 are within 17% and 15% of the observed conditions, respectively. The differences between the observed and estimated conditions in Pool 6 may be due to differences in discharge conditions. Another potential issue specific to Pool 6 was that no spatial elevation data was available at the time of the estimate (i.e., in 2004 when the NESP Report 53 was being written), which meant that HEC-RAS cross section data had to be used to estimate the area exposed.

The acres exposed numbers presented here are the maximum acres exposed at any given time. However, the acres that are exposed can shift within the pool depending on river flows such that different areas might be affected under certain hydrologic conditions and even over the course of a season. This may result in more or less overall acres exposed. In general, when river flows are lower, the exposed areas tend to shift toward the upper end of the pool, while during higher river flows, the lower portion of the pool is more affected. This is due to the slight tilt of the water surface. This was experienced during the 2005 drawdown in Pool 5 where during the first month of drawdown, approximately 1,000 acres were exposed in the lower portion of the pool. When river discharge was decreased at the end of July, pool operations shifted to maintain the navigation channel and resulted in an additional 1,000 acres being exposed in the middle and upper portions of the pool (Nissen 2014).

4.4.2 Ecosystem Benefits Quantification

Quantifying the ecological outputs is a new section associated with this report update. Previous studies have evaluated drawdown benefits using a simple measure of the number of acres anticipated to be exposed by the drawdown, with the assumption being that the land area exposed is likely to experience improved aquatic vegetation growth following the drawdown. However, the number of acres exposed does not provide a clear or comparable measure of the increase in ecosystem value that a drawdown provides.

The purpose of the ecosystem benefits quantification is to evaluate WLM in terms of its potential "net contributions to increases in ecosystem value." This is how the Corps evaluates ecosystem restoration projects such as Habitat Rehabilitation and Enhancement Projects (HREPs) under the UMRR Program. This analysis provides a link between the acres exposed and the ecosystem benefits expected for WLM and gives the ability to compare the results to other ecosystem restoration projects like island construction or hydraulic modifications.

This analysis uses the Habitat Evaluation Procedure (HEP) method developed by the USFWS (1980) to evaluate the effects of drawdowns on each pool. The HEP method uses Habitat Suitability Index (HSI) models developed for species of interest to quantify the habitat value of an area for those species at a specific time. The Dabbling Duck Migration Model for the Upper Mississippi River (Devendorf 2013) was selected as the HSI model most appropriate to evaluate the effects of drawdowns. This model has been used successfully for many UMRS habitat restoration projects. The HEP methodology provides a framework for combining the habitat suitability, area affected, anticipated costs of the drawdowns and length of effect. This can be a powerful tool to prioritize drawdowns and compare them to other ecosystem restoration actions being considered.

HEP modeling is a process intended to simplify and compare the expected habitat benefits and costs of projects. It uses a surrogate species or guild of species to represent habitat benefits. This form of habitat modeling is not intended to capture all of the ecological benefits a project might have.

Methods

Habitat Suitability Index (HSI) Modeling

The Dabbling Duck Migration Model is a Corps certified model used to quantify and evaluate fall migration habitat quality on large river systems (Devendorf 2013). The model was selected to capture ecosystem benefits derived from WLM action because of the variables associated with the model (e.g., aquatic vegetation diversity and abundance, percent open water, and habitat structures). The model includes 11 variables described in Table 4.7. Each variable is scored on a scale of 5 or 10, summed together and then divided by a sum total of 85 to generate the HSI, which can range from 0 (completely unsuitable) to 1 (perfect habitat).

Table 4.7: Dabbling Duck Migration Model variables

1) Distance to bottomland hardwoods	7) Important food plant coverage
2) Distance to cropland and cropland practices	8) Percent of area containing loafing structures
3) Water depth 4-18 inches in the fall	9) Structure to provide thermal protection
4) Water depth <4 inches in the fall	10) Disturbance in the fall
5) Percent open water	11) Visual barriers
6) Plant community diversity	

The Dabbling Duck Migration Model requires information regarding water depths and the type and extent of vegetation communities currently present and those predicted to be present within the evaluation area. Because of the large scale of the evaluation area, it was only practical to use existing data. Fortunately, many high-quality, large-scale datasets are available for the UMRS (Appendix F). These datasets were used to assign a rating to each of the 11 variables for existing conditions.

For the Future with Project conditions (i.e., with WLM), spatial data from the Acres Exposed analysis (Chapter 4.4.1) were used to identify the specific locations where dewatering would occur in each pool under each drawdown scenario. Predictions were made about how vegetation would grow in relation to the dewatered areas. Three primary assumptions were used:

(1) All areas that are unvegetated or sparsely vegetated under normal conditions and become exposed under drawdown conditions would grow emergent vegetation.

    This assumption is based on the results and observations of past drawdowns. Perennial emergent vegetation has been the most consistent documented vegetation response. Only unvegetated or sparsely vegetated areas were included to avoid double-counting areas that already have existing aquatic vegetation.

(2) An area equal to the exposed unvegetated areas will grow a 50/50 mix of submersed aquatic vegetation and rooted floating aquatic vegetation.

    This assumption was developed because areas outside of the de-watered zones would benefit from an increased photic zone. This benefit is not captured in the "acres exposed" data generated for this analysis and developing this data would be time consuming across all pools and drawdown scenarios by essentially doubling the work. This assumption has two components – area of effect and plant species. The exposed area (see assumption 1 above) was used as a surrogate for the area of improved photic zone by assuming a similar slope down the riverbed and backwater areas within the shallow areas affected by drawdowns. For species, past drawdowns have resulted in increases in submersed aquatic vegetation and rooted floating aquatic vegetation (Nissen 2014). It is recognized that there will naturally be variation in vegetation response. Past drawdown vegetation response has been correlated to the seedbank in the exposed areas.

(3) For the Dabbling Duck Model Variable 7 "Important Food Plant Coverage," all new acres of vegetation grown due to drawdowns will contain important waterfowl food plant species. This assumption is based on a review of results of past drawdowns in Pools 5, 6, 8, 24, 25, and 26. Vegetation monitoring results post-drawdown nearly always indicated that important food plant species were a majority of the species growing in the affected areas.

For the Future with Project conditions (i.e., following a drawdown), only three variables were re-calculated: V5) Percent Open Water, V6) Plant Community Diversity, and V7) Important Food Plant Coverage. These three variables were the only ones reliably measurable using available data and the primary assumptions of drawdown effects. While we assume that positive changes would also occur to some of the other variables, an effective and straightforward way to measure the changes across the UMRS could not be identified. Therefore, the Future with Project conditions assumes that all other variables remain the same as existing conditions. This may result in an underestimate of habitat benefit.

Modeling was conducted on a pool-by-pool basis, using the UMESC Land Classification dataset's floodplain boundaries as the extent for evaluation of each pool. Analysis tools used include Environmental Systems Research Institute (ESRI) ArcMap and the following ArcGIS components: ModelBuilder, Spatial Analyst Extension, SQL, and Python scripts. Additional details on the GIS techniques used can be found in Appendices F and G.

Habitat Evaluation Procedures (HEP) Assumptions

The HEP procedures allowed the HSI results to be applied over a 50-year planning period. For future conditions, both with and without drawdowns, assumptions were developed to make predictions of when, where, and how vegetation communities would change through time. Six primary assumptions were used:

(1) No change in future vegetation conditions, except for those resulting drawdowns. HEP modeling frequently incorporates predictions of future conditions. Not enough information was available to systematically predict vegetation trends. Therefore, only predicted effects of drawdowns are considered here.

(2) A 50-year planning period is used. This was selected to match the typical planning period used in Corps' restoration projects.

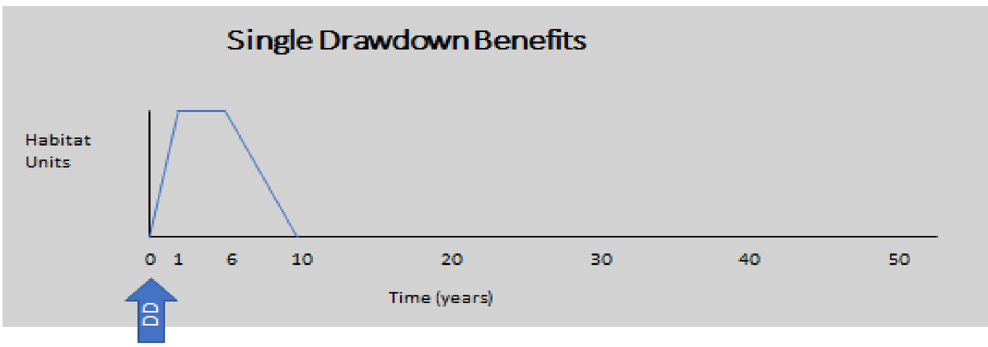
(3) Habitat benefits were applied temporally within the 50-year planning period as follows. Full habitat benefits and vegetation increases would be realized within a year of the drawdown event (year 0-1). Full benefits would persist for 5 years (years 1-6). Benefits would then decline back to baseline conditions over 4 years (years 6-10). The periods of increasing and decreasing benefits were applied in the Dabbling Duck Model calculations as linear changes between baseline and full benefit (Figure 4.4). These assumed benefit timeframes were based on vegetation monitoring after drawdowns in Pool 5, where perennial emergent plants were documented for persisting at least 4 years, and in Pool 8 where perennial emergent plants were documented as lasting at least 6 years (Nissen 2014).

(4) Drawdown costs were incorporated from the analysis in Chapter 4.2.1, the estimated dredging and dredged material management costs. Assumptions regarding cost estimation are still applicable in this analysis.

(5) Costs were annualized over the 50-year planning period using the current discount rate of 2.5%.

(6) Drawdowns are typically attempted two successive seasons if the dredging holds and conditions allow. This evaluation does not consider the second drawdown as critical for influencing benefits.

Figure 4.4: Conceptual depiction of habitat unit benefits over a 50-year planning period associated with a single drawdown. The x-axis represents the baseline conditions of any given pool and the blue line represents the habitat improvements following a single drawdown at year 0.



Results

HSI Modeling - Dabbling Duck

Results of the Dabbling Duck Migration Model were calculated for the selection of MVP and MVR pools at four different drawdown depths: 0.5, 1, 1.5, and 2 feet (Table 4.8). HSI scores are a maximum of 1. The lowest score for existing conditions (Future without Project Condition) was for Pool 2 with 0.24 while Pool 5A had the highest score pool at 0.59. These results agree with resource manager opinions on the ecological condition of the pools.

Generally, WLM produced the greatest potential increases in habitat value in those pools that ranked lowest in habitat values under existing conditions. The highest percentage increases in habitat values are 75%, 59%, and 59% for Pools 2, 18, and 21, respectively. The lowest increases in HSI values were in Pools 5A, 10, and 12 increasing by 0%, 0%, and 4%, respectively.

Table 4.8: Dabbling Duck Migration Model HSI Results

Pool	Existing Conditions/ Future Without Project	Future With Project: 0.5' Drawdown	Future With Project: 1' Drawdown	Future With Project: 1.5' Drawdown	Future With Project: 2' Drawdown
2	0.24	0.38	0.40	0.42	0.42
3	0.49	0.52	0.52	0.52	0.52
5	0.55	0.55	0.55	0.55	0.58
5A	0.59	0.59	0.59	0.59	0.59
6	0.48	0.54	0.54	0.54	0.54
7	0.54	0.54	0.54	0.58	0.58
8	0.53	0.56	0.56	0.61	0.61
9	0.55	0.58	0.58	0.58	0.58
10	0.47	0.47	0.47	0.47	0.47
11	0.45	0.45	0.49	0.49	0.49
12	0.46	0.45	0.48	0.48	0.48
13	0.51	0.56	0.56	0.56	0.56
16	0.27	0.38	0.40	0.40	0.42
18	0.32	0.46	0.46	0.48	0.51
19	0.34	0.45	0.47	0.47	0.49
21	0.29	0.36	0.39	0.44	0.46
22	0.27	0.31	0.34	0.34	0.34
Starved Rock	0.29	0.40	0.36	0.39	0.45

HEP Evaluation

The HSI results above were used to calculate habitat units for each pool under existing conditions and for each drawdown scenario, assuming a single drawdown event at year 0 (Appendix H). A selection of full model outputs is presented in Table 4.9. Three pools were selected in different reference conditions to show a range of habitat unit outputs - Pools 2, 8, and 5. Pool 2 is an example of a pool with large habitat improvements and average dredging costs. Pool 8 is an example of medium habitat improvements and a fairly high dredging cost. Pool 5 exhibits minimal habitat improvements (due to already high habitat value and substantial aquatic vegetation), and also represents the highest dredging costs of any pool evaluated. The results of the remaining MVR and MVP pools can be found in Appendix I.

Table 4.9: Habitat Evaluation Procedures Results for Select UMR Pools 2, 5, and 8.

			Pool 2					Pool 8					Pool 5				
			Existing	0.5	1.0	1.5	2.0	Existing	0.5	1.0	1.5	2.0	Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables																	
5	Percent Open Water	*max 10*	1	5	7	7	7	7	10	10	10	10	10	10	10	10	10
6	Plant Community Diversity	*max 10*	1	4	4	4	4	6	6	6	10	10	4	4	4	4	6
7	Important food plant coverage	*max 10*	0.5	6	6	8	8	10	10	10	10	10	8	8	8	8	8
	TOTAL	*max 85*	19.5	32	34	36	36	45	48	48	52	52	47	47	47	47	49
	HSI	*total/85*	0.23	0.38	0.40	0.42	0.42	0.53	0.56	0.56	0.61	0.61	0.55	0.55	0.55	0.55	0.58
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window																	
	Acres		25332	25332	25332	25332	25332	45316	45316	45316	45316	45316	16361	16361	16361	16361	16361
	Period of Evaluation (years)		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Average Annual Habitat Units (AAHU)		5811.5	9536.8	10132.8	10728.8	10728.8	23990.8	25590.2	25590.2	27722.7	27722.7	9046.7	9046.7	9046.7	9046.7	9431.6
	AAHUs annualized across 50 years		-	6370.3	6459.7	6549.1	6549.1	-	24230.7	24230.7	24550.6	24550.6	-	9046.7	9046.7	9046.7	9104.4
	AAHU Gain		-	558.8	648.2	737.6	737.6	-	239.9	239.9	559.8	559.8	-	0.0	0.0	0.0	57.7
Cost/Benefit Comparison																	
	Total AAHUs		-	558.8	648.2	737.6	737.6	-	239.9	239.9	559.8	559.8	-	0.	0.	0.	57.7
	Estimated Dredging Costs		-	$ 1,350,000	$ 2,070,000	$ 2,800,000	$ 3,520,000	-	$ 1,880,000	$ 2,660,000	$ 3,440,000	$ 5,240,000	-	$ 3,760,000	$ 4,840,000	$ 5,940,000	$ 7,040,000
	Annualized Cost (2.5% discount rate)		-	$ 48,000	$ 73,000	$ 99,000	$ 124,000	-	$ 66,000	$ 94,000	$ 121,000	$ 185,000	-	$ 133,000	$ 171,000	$ 209,000	$ 248,000
	Cost per Average Annual Habitat Unit		-	$ 85	$ 113	$ 134	$ 168	-	$ 276	$ 391	$ 217	$ 330	-	N/A	N/A	N/A	$ 4,299

Notes

(1) Dabbling Duck HSI value for each alternative equals the sum of each of the variables divided by the maximum potential score (85).

(2) Dabbling Duck HSI values shown are rounded to the nearest hundredth. However, rounding is only applied for display purposes, and was not incorporated into the AAHU calculation.

(3) Modeling does not account for deterioration of existing conditions. Benefits would be increased by accounting for the "Future Without Project" conditions.

(4) A one-year establishment period for project-related vegetation growth and establishment in order to experience full benefit levels. During this period, AAHU benefits for the Dabbling Duck were interpolated as a linear gain from existing conditions to project conditions.

(5) Total Project Cost and Annualized Cost estimates rounded to the nearest $1,000.

(6) The only variables assessed for change due to drawdown in this preliminary model run were Variables 5, 6, and 7. These were measurable using available data. Other variables like 8, 9, and 11 would likely be improved as well

Table 4.10 summarizes the cost per Average Annual Habitat Unit (AAHU) for each pool evaluated. As shown on Table 4.8, not all drawdown levels resulted in incremental increases in habitat units, and this also affects the AAHU calculations. For example, in Pool 2, the 2-foot drawdown produced the same HSI value as the 1.5-foot drawdown. Therefore, both drawdowns produce the same number of AAHUs for different costs. The cost per AAHU on Table 4.10 is shown in red when the output was the same as the lower level of drawdown. A similar situation exists where the Dabbling Duck Model returned the same HSI for existing conditions and the 0.5-foot drawdown condition (e.g., Pools, 5, 5A, etc.). A cost per habitat unit cannot be calculated until there has been an increase in habitat units observed from existing conditions, and these cells are therefore blank.

Table 4.10: Cost per Average Annual Habitat Unit for all Pools Evaluated

Pool	Cost per Avg. Annual Habitat Unit (AAHU) *Drawdown Amount (Feet)* 0.5	1.0	1.5	2.0
2	$ 85	$ 113	$ 134	$ 168
3	$ 735	$ 1,272	$ 1,805	$ 2,938
5				$ 4,299
5A				
6	$ 118	$ 167	$ 213	$ 261
7			$ 560	$ 745
8	$ 276	$ 391	$ 217	$ 330
9	$ 161	$ 165	$ 170	$ 174
10				
11		$ 194	$ 344	$ 323
12	$ 95	$ 209	$ 322	$ 435
13	$ 42	$ 120	$ 196	$ 281
16	$ 129	$ 198	$ 170	$ 171
18	$ 11	$ 38	$ 43	$ 52
19	*No cost*	$ 5	$ 6	$ 8
21	$ 97	$ 185	$ 139	$ 178
22		$ 263	$ 444	$ 633
Starved Rock	$ 142	$ 201	$ 249	$ 397

** Blank cells and red values both indicate no HSI benefit was captured at these drawdown levels compared to existing conditions or the previous drawdown. See description in text.*

Discussion

The three pool scenarios presented show a representative range of HSI results from the dabbling duck modeling exercise. In general, the benefits were greater (i.e., the increase in variables V5-V7) for pools that started in a more degraded condition, and with less aquatic vegetation (Table 4.9).

The cost per AAHU varies widely among habitat projects. However, costs ranging from $2,000 - $5,000 per AAHU are typical for contemporary restoration projects in the UMRS. By contrast, the cost per AAHU calculated for growing season drawdowns in many of the pools are significantly lower. For example, the cost per AAHU calculated for drawdowns in pools with a large habitat improvement (e.g., Pools 2, 16, 18, 19, 21, or Starved Rock) ranged from $5 to $397 per AAHU. For pools with moderate habitat improvements (e.g., Pools 3, 7, 8, 11) ranged from $217 to $735 per AAHU. Nearly all drawdown scenarios evaluated were under $1,000 per AAHU. The highest cost per AAHU was the 2-foot drawdown scenario for Pool 5, costing $4,299 per AAHU, which was due to marginal habitat improvements and the highest dredging costs of any pool evaluated. The only other alternatives over $1,000 per AAHU were the 1.0, 1.5, and 2.0-foot drawdowns in Pool 3, where benefits were not captured in the model beyond the 0.5-foot alternative. These costs still remain within the range of reasonable costs from previous projects. Only two pools did not realize any habitat benefits in this HSI modeling – Pools 5A and 10 – which meant that no cost per AAHU could be determined for drawdowns in these pools. Based on these results, it appears that the costs of habitat benefits of growing season drawdowns are almost always much lower than typical habitat restoration projects.

It is important to keep in mind that the habitat benefits identified in this report do not represent the full range of ecological benefits provided by drawdowns. As noted, the benefits documented in this report consist only of those that are measured by the dabbling duck model, and that this group of species is being used as a surrogate for representing large-scale habitat improvements that would benefit a wide variety of species. (e.g., fish, invertebrates). Likewise, no potentially adverse impacts are included within the model. It is also important to recognize that because this exercise was simplified to apply to all pools, there was no accounting for the habitat changes in the absence of drawdowns. In pools where the habitat and vegetation may change into the future, the benefits of water level management would be more or less pronounced depending on whether aquatic vegetation is trending up or down into the future. This model framework could provide a good starting point for a project development team[6] to more carefully evaluate the effects of drawdowns within a pool of interest.

Another consideration not included in the quantification of habitat benefits are the drawdown success rates. Different pools and different levels of drawdown scenarios vary in their chance of successfully performing a drawdown in any given year (see Chapter 4.3). When choosing to implement a drawdown, the costs of dredging and preparing the navigation channel for lower water levels are incurred before the drawdown can be conducted, resulting in some level of risk. These probabilities could be considered for incorporation into the habitat benefit calculations to see how the relative risk affects the benefits. For example, if a pool has a chance of success of 50%, a simple way to incorporate this risk might be to assume that the dredging may have to be done twice in order to achieve the drawdown benefits desired.

[6] Project development teams work together to determine the feature of a restoration project. Members include Corps staff, project sponsors and agencies with jurisdiction on the river (e.g., state agencies, USFWS)

Chapter 5. Conclusions

The evaluations of success rates, costs, acres exposed, and ecological benefits for each pool presented in this report are intended to support the planning, development, and prioritization of future WLM investigations and actions. It is highly likely that subsequent site-specific feasibility investigations would result in nuances in implementation and site-specific constraints that would impact the expected benefits, costs, and success rates of future water level management actions. Still, there are many informative conclusions that can be drawn from the analyses presented in this report.

For the ecological benefits analysis, the cost per AAHU is lower for WLM relative to UMRR HREPs and provides support for utilizing WLM as an ecosystem restoration tool. The results suggest that pools with less vegetation have more to gain. However, there is still a learning opportunity to understand how WLM can bring a pool out of a degraded state and how often the tool should be implemented for building resilience both throughout the UMRS and pools considered to be in “good” ecological condition.

The SDM workshop process to discuss ecological goals and objectives for WLM action was successful in increasing partnership agreement on values and fundamental objectives of WLM, operationalizing WLM and how to assess it with performance measures, and consequences and tradeoffs to various alternatives for implementing WLM.

Next steps for this work include the following:

- Carry out the recommendations of the SDM workshop series (see Section 3.1)
- Explore policy and administrative hurdles to WLM implementation
- Advocate for WLM action with Corps authorities and programs

Opportunities

Future opportunities to implement WLM concurrently with opportunities such as UMRR HREP construction or coinciding with the beneficial use of dredge material should be coordinated and sought after. These opportunities have the potential to increase WLM feasibility, cost effectiveness and ecological or beneficial use of materials.

There are many learning opportunities for WLM including pre- and post-implementation monitoring protocols and designing additional rigorous studies (e.g., Before-After Control-Impact (BACI), see Christie et al. 2019) to inform future activities, further refine assumptions, benefits, challenges and costs, risks, and successes.

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Appendices

Appendix A

WLM PAS Agreement with UMRBA and the Army Corps of Engineers

AGREEMENT
BETWEEN
THE DEPARTMENT OF THE ARMY
AND
UPPER MISSISSIPPI RIVER BASIN ASSOCIATION
FOR DEVELOPMENT OF A COMPREHENSIVE PLAN

THIS AGREEMENT is entered into this 20th day of February, 2018, by and between the Department of the Army (hereinafter the "Government"), represented by the U.S. Army Engineer, St. Paul District (hereinafter the "District Engineer") and the Upper Mississippi River Basin Association (hereinafter the "Non-Federal Sponsor"), represented by the Executive Director.

WITNESSETH, THAT:

WHEREAS, Section 22 of the Water Resources Development Act of 1974, as amended (42 U.S.C. 1962d-16) authorizes the Secretary of the Army, acting through the Chief of Engineers, to provide assistance in the preparation of a comprehensive water resources plan (hereinafter the "Plan") to a State or non-Federal interest working with a State, and to establish and collect fees for the purpose of recovering 50 percent of the costs of such assistance except that Secretary may accept and expend non-Federal funds provided that are in excess of such fee; and

WHEREAS, the Government and the Non-Federal Sponsor have the full authority and capability to perform in accordance with the terms of this Agreement.

NOW, THEREFORE, the parties agree as follows:

1. The Government shall develop the plan, in coordination with the Non-Federal Sponsor, in accordance with the attached Scope of Work, and any modifications thereto, that specifies the scope, cost, and schedule for activities and tasks, including the Non-Federal Sponsor's in-kind services.

2. The Non-Federal Sponsor shall provide 50 percent of the costs for developing the Plan in accordance with the provisions of this paragraph. As of the effective date of this Agreement, the costs of developing the Plan are projected to be $360,000, with the Government's share of such costs projected to be $180,000 and the Non-Federal Sponsor's share of such costs projected to be $180,000, which includes estimated credit in the amount of $180,000 for in-kind services.

a. After considering the estimated amount of credit for in-kind services that will be afforded in accordance with paragraph 4, if any, the Government shall provide the Non-Federal Sponsor with a written estimate of the amount of funds required from the Non-Federal Sponsor for the initial fiscal year of development of the Plan, with a fiscal year beginning on October 1st and ending on September 30th of the following year. No later than 15 calendar days after such notification, the Non-Federal Sponsor shall provide the full amount of such funds to the Government by delivering a check payable to "FAO, USAED, St. Paul District (B6)" to the District Engineer or by providing an Electronic Funds Transfer of such required funds in accordance with procedures established by the Government.

b. No later than August 1st prior to each subsequent fiscal year during development of the Plan, the Government shall provide the Non-Federal Sponsor with a written estimate of the amount of funds required from the Non-Federal Sponsor during that fiscal year. No later than September 1st prior to that fiscal year, the Non-Federal Sponsor shall provide the full amount of such required funds to the Government using one of the payment mechanisms specified in paragraph 2.a. above.

c. If the Government determines at any time that additional funds are needed from the Non-Federal Sponsor to cover the Non-Federal Sponsor's costs of developing the Plan, the Government shall provide the Non-Federal Sponsor with written notice of the amount of additional funds required. Within 60 calendar days of such notice, the Non-Federal Sponsor shall provide the Government with the full amount of such additional funds.

d. Upon completion of the Plan and resolution of any relevant claims and appeals, the Government shall conduct a final accounting and furnish the Non-Federal Sponsor with the written results of such final accounting. Should the final accounting determine that additional funds are required from the Non-Federal Sponsor, the Non-Federal Sponsor, within 60 calendar days of written notice from the Government, shall provide the Government with the full amount of such additional funds. Should the final accounting determine that the Non-Federal Sponsor has provided funds in excess of its required amount, the Government shall refund the excess amount, subject to the availability of funds. Such final accounting does not limit the Non-Federal Sponsor's responsibility to pay its share of costs, including contract claims or any other liability that may become known after the final accounting.

3. In addition to its required cost share, the Non-Federal Sponsor may determine that it is in its best interests to provide additional funds for development of the Plan. Additional funds provided under this paragraph and obligated by the Government are not included in calculating the Non-Federal Sponsor's required cost share and are not eligible for credit or repayment.

4. The in-kind services includes those activities (including services, materials, supplies, or other in-kind services) that are required for development of the Plan and would otherwise have been undertaken by the Government and that are specified in the Scope of Work and performed or provided by the Non-Federal Sponsor after the effective date of this Agreement and in accordance with the Scope of Work. The Government shall credit towards the Non-Federal Sponsor's share of costs, the costs, documented to the satisfaction of the Government, that the Non-Federal Sponsor incurs in providing or performing in-kind services, including associated supervision and administration. Such costs shall be subject to audit in accordance with paragraph 9 to determine

reasonableness, allocability, and allowability, and crediting shall be in accordance with the following procedures, requirements, and limitations:

a. As in-kind services are completed and no later than 60 calendar day after such completion, the Non-Federal Sponsor shall provide the Government appropriate documentation, including invoices and certification of specific payments to contractors, suppliers, and the Non-Federal Sponsor's employees. Failure to provide such documentation in a timely manner may result in denial of credit. The amount of credit afforded for in-kind services shall not exceed the Non-Federal Sponsor's share of costs.

b. No credit shall be afforded for interest charges, or any adjustment to reflect changes in price levels between the time the in-kind services are completed and credit is afforded; for the value of in-kind services obtained at no cost to the Non-Federal Sponsor; or for costs that exceed the Government's estimate of the cost for such item if it had been performed by the Government.

5. The Non-Federal Sponsor shall not use Federal Program funds to meet any of its obligations under this Agreement unless the Federal agency providing the funds verifies in writing that the funds are authorized to be used for the Plan. Federal program funds are those funds provided by a Federal agency, plus any non-Federal contribution required as a matching share therefor.

6. In carrying out its obligations under this Agreement, the Non-Federal Sponsor shall comply with all the requirements of applicable Federal laws and implementing regulations, including, but not limited to: Title VI of the Civil Rights Act of 1964 (P.L. 88-352), as amended (42 U.S.C. 2000d), and Department of Defense Directive 5500.11 issued pursuant thereto; the Age Discrimination Act of 1975 (42 U.S.C. 6102); and the Rehabilitation Act of 1973, as amended (29 U.S.C. 794), and Army Regulation 600-7 issued pursuant thereto.

7. Upon 30 calendar days written notice to the other party, either party may elect, without penalty, to suspend or terminate further development of the Plan. Any suspension or termination shall not relieve the parties of liability for any obligation incurred.

8. As a condition precedent to a party bringing any suit for breach of this Agreement, that party must first notify the other party in writing of the nature of the purported breach and seek in good faith to resolve the dispute through negotiation. If the parties cannot resolve the dispute through negotiation, they may agree to a mutually acceptable method of non-binding alternative dispute resolution with a qualified third party acceptable to the parties. Each party shall pay an equal share of any costs for the services provided by such a third party as such costs are incurred. The existence of a dispute shall not excuse the parties from performance pursuant to this Agreement.

9. The parties shall develop procedures for the maintenance by the Non-Federal Sponsor of books, records, documents, or other evidence pertaining to costs and expenses for a minimum of three years after the final accounting. The Non-Federal Sponsor shall

assure that such materials are reasonably available for examination, audit, or reproduction by the Government.

a. The Government may conduct, or arrange for the conduct of, audits of the Plan. Government audits shall be conducted in accordance with applicable Government cost principles and regulations. The Government's costs of audits for the Plan shall not be included in the shared costs of the Plan, but shall be included in calculating the overall Federal cost of the Plan.

b. To the extent permitted under applicable Federal laws and regulations, the Government shall allow the Non-Federal Sponsor to inspect books, records, documents, or other evidence pertaining to costs and expenses maintained by the Government, or at the request of the Non-Federal Sponsor, provide to the Non-Federal Sponsor or independent auditors any such information necessary to enable an audit of the Non-Federal Sponsor's activities under this Agreement. The costs of non-Federal audits shall be paid solely by the Non-Federal Sponsor without reimbursement or credit by the Government.

10. In the exercise of their respective rights and obligations under this Agreement, the Government and the Non-Federal Sponsor each act in an independent capacity, and neither is to be considered the officer, agent, or employee of the other. Neither party shall provide, without the consent of the other party, any contractor with a release that waives or purports to waive any rights a party may have to seek relief or redress against that contractor.

11. Any notice, request, demand, or other communication required or permitted to be given under this Agreement shall be deemed to have been duly given if in writing and delivered personally or mailed by certified mail, with return receipt, as shown below. A party may change the recipient or address for such communications by giving written notice to the other party in the manner provided in this paragraph.

If to the Non-Federal Sponsor:
Upper Mississippi River Basin Association
Kirsten Mickelsen
408 St. Peter Street, Suite 418
St. Paul, MN 55102

If to the Government:
Chief, Project Management and Development Branch
U.S. Army Corps of Engineers, St. Paul District
180 Fifth Street E. Suite 700, St. Paul, MN 55101

12. To the extent permitted by the laws governing each party, the parties agree to maintain the confidentiality of exchanged information when requested to do so by the providing party.

13. Nothing in this Agreement is intended, nor may be construed, to create any rights, confer any benefits, or relieve any liability, of any kind whatsoever in any third person not a party to this Agreement.

IN WITNESS WHEREOF, the parties hereto have executed this Agreement, which shall become effective upon the date it is signed by the District Engineer.

DEPARTMENT OF THE ARMY	UPPER MISSISSIPPI RIVER BASIN ASSOCIATION
BY: [signature]	BY: [signature]
SAMUEL L. CALKINS COL, U.S. Army District Engineer	KIRSTEN MICKELSEN Executive Director
DATE: February 20, 2018	DATE: February 16, 2018

Appendix B

Summary notes from the Water Level Management Task Force (WLMTF) November 2019 meeting on MVP pool selection.

WLMTF – November 5, 2019 Meeting

Evaluation of St. Paul District Pools for NESP Report 53 update

The NESP Report 53 publication included UMR Pools 5, 7, 8, and 9. The WLMTF agreed that Pools 2, 3, and 10 should be reconsidered. The rationale for excluding pools is also detailed below, denoted by "In" and "Out".

Upper and Lower St Anthony Falls (Out)

Constraints:

- Numerous stakeholders in the Twin Cities Metro Area
- Hydropower production
- Not enough floodplain to expose as the area is a gorge

Pool 2 (In)

Opportunities:

- Chances of a successful drawdown are high because of the way the gates are operated (i.e., the L&D is situated higher on the landscape and gates are pulled out for a 3-4-year flood event)
- While it could be challenging to grow aquatic vegetation, there are floodplain forests, a few islands and backwaters (e.g., Spring, Baldwin, Pig's Eye Lakes) that may be positively impacted

Constraints:

- Re the question of discharge from the Minnesota River, the potential challenge isn't unique to pool 2. Most constraints are above the control point.
- There is a huge barge fleeting area on this pool, but a few participants agreed they would not be affected so long as there is no change at the control point
- Most of the dredging occurs in the lower portion of the pool. Pool 2 is the third most dredged in the district, and material placement is a concern.
- A vocal stakeholder could be the St. Paul Yacht Club as they have been in prior experiences. On the other hand, they are supporters of ecosystem restoration.

Pool 3 (In)

Opportunities:

- For a 30 day drawdown, the chances of success are higher. A drawdown of 6 inches is believed to be effective.
- A successful drawdown may positively benefit aquatic vegetation and floodplain forests.

Constraints:

- Lower probability of success because of flashiness of the upper pool 4. A drawdown of 2 feet could impact Lake St. Croix all the way up to Stillwater. This is because the control point is at Prescott.
- Stakeholders of concern include: Xcel nuclear plant below pool 3, the city of Diamond Bluff, and Prairie Island marina.

Pool 4 (Out)

Constraints:

- Lake Pepin and Chippewa River sediment load

[However, the pool should be given consideration if new technology comes about in the future].

Pool 5 (In)

Opportunities:

- Successful drawdown in 2005/2006; success is high due to dam operation
- During the recent HREP selection process, a factsheet was proposed for WLM

Constraints:

- Second highest dredging in the District and placement of dredge material is a concern

Pool 5A (In)

Opportunities:

- Benefits to aquatic vegetation and to floodplain forests
- Only two dredge cuts in the pool (i.e., Wild's Bend and Betsy Slough)

Constraints:

- USACE Fountain City Service Station
- Pool is flashy; low chance of success due to the amount of time gates are out of the water

Pool 6 (In)

Opportunities:

- Initiated a drawdown in 2010
- benefits to aquatic vegetation and to floodplain forests

Constraints:

- Marinas in the drawdown zone
- Dredging is trending up in the pool

Pool 7 (In)

Opportunities:

— Potential floodplain forest benefits

Constraints:

— Majority of dredging is in the bottom of the pool

— High public use areas e.g., Lake Onalaska

— Out draft at the upper lock approach

— Some would say there is too much vegetation, especially in Lake Onalaska

— Vocal stakeholders may include the La Crosse Sailing Club

Pool 8 (In)

Opportunities:

— Successful drawdowns in 2001 and 2002

— Preliminary Informational Assessment was completed in May 2017 by MVP (white paper)

Constraints:

— Ensure the gauge in La Crosse is functioning.

Pool 9 (In)

Opportunities:

— Letter Report was completed in early 2003

— Dredge material from the Lansing bridge beneficial use site is in demand

Constraints:

— Cultural resource concerns

Pool 10 (In)

Opportunities:

— Potential for opportunistic drawdowns due to configuration of the pool

Constraints:

— Significant dredging in the lower portion of the pool

— One of the current authorities for WLM would require a re-write the L&D 10 water control plan

Appendix C

Summary notes from the Fish and Wildlife Interagency Committee (FWIC) March 2020 meeting on MVR pool selection

Summary of Rock Island Pool Selection and Discussion with the FWIC

March 5, 2020

On behalf of the WLM Regional Coordinating Committee, UMRBA requested the FWIC's input on selecting pools within the Rock Island District to evaluate through a larger update to the NESP report 53 (i.e., sections on dredging required, success rate, and acres exposed). Appendix C of the NESP Environmental Report 53 was sent to the FWIC for reference. It includes the suitability criteria developed by the FWIC WLM workgroup to prioritize WLM in 2004.

Participants generally agreed to maintain the 2004 list of pools i.e., Pools 11, 13, 16, 18, and 19. The FWIC agreed to this selection given the limited available PAS funds [7], If additional funding was made available, some FWIC participants shared their preferences to use dredging and success rates to determines priorities among all MVR pools.

Additional discussion included whether to maintain Pools 11 and 13, given that UMRR HREP s are under planning with WLM as a project feature. The UMRR Coordinating Committee endorsed Lower Pool 11 to be implemented in FY 2021-2025. It has yet to be approved by MVD. The PDT for the UMRR Lower Pool 13 HREP is still determining whether to move WLM forward as a project feature. The data collected for Pool 13 could either be done through the Lower Pool 13 HREP or the UMRBA-USACE PAS agreement.

Ultimately, participants suggested that the UMRBA-USACE PAS evaluate FWIC's 2004 list and UMR Pools 12, 20, 21, and 22, and IWW Starved Rock pool. The discussion associated with each pool is below.

Pool 12 – Iowa DNR expressed interest seeing WLM considered in Pool 12 because of the significant ecological benefits. The success rate criteria for L&D 12 is rated low but all other categories were rated high.

L&D 12 goes out of operation at 94,000 cubic feet per second (cfs), which is a low value compared to L&D 11 at 135,000 cfs and L&D 13 at 131,000 cfs. There is a limited ability to manager water at high discharge.

Pools 20 to *22* – During periods of higher flows, Ameren still has an impact on Pools 20-22. Pool 20 is heavily influenced by hydropower at L&D 19 and the Des Moines River, so the dam goes out of operation pretty quickly. Pools 21 and 22 are heavily leveed but stay in operation longer than Pool 20. Quincy Bay is in Pool 21 where residents are likely to be oppositional, because the bay would become too shallow for recreation. Pool 22 has industry and there will likely be problem spots for those stakeholders. The habitat in Pool 22 has the most potential for ecological benefits due to the number of side channels and it has less recreation users and overall conflicts than the other pools.

[7] The costs for updating dredging required and success rate is a flat rate regardless of the number of pools and scenarios. The cost for estimating acres exposed is additive with each scenario and pool. Therefore, the PAS is limited on the number of pools that can be evaluated.

Starved Rock – The interest in reconsidering Starved Rock pool is in part because of the planned navigation closures for lock rehabilitation on the IWW from 2019 to 2023. Barge traffic will be minimized and a reduction in suspended solids could lead to a positive SAV response.
One observation was that ecosystem benefits in the NESP report update may provide a higher benefit-cost ratio and therefore, more a positive favoring of the WLM. The information from the ILWW Comprehensive Plan indicated that the available acreage within Starved Rock pool was pretty low. There is an approved (but not yet constructed) restoration project to construct rock dykes to mitigate toe and wind generative waves, that is expected to positively benefit SAV. The challenges to implementing WLM in the Starved Rock pool include the effects of precipitation upstream in Chicago, potential impacts to a marina, and a hydropower facility.

Appendix D - Estimating Dredging Required to Conduct Drawdowns

General Concept

Note that definitions used in methodology description are immediately following.

To determine the additional dredging that is needed for various levels of drawdown, LCP DD has to be determined and subtracted from LCP Routine to determine the additional dredge cut depth. For routine water management, LCP is used to determine how deep to dredge the navigation channel at each dredge cut. For a drawdown, the additional dredge cut depth has to be included in the dredging quantities.
LCP DD is determined using linear interpolation based on the lowest drawdown at the dam for the four drawdown scenarios and the lowest drawdown at the control point. For dam point control, LCP throughout the pool was set equal to the water surface profile for the discharge exceeded 95% of the time in that pool based on CWMS simulations. The interpolated additional dredge cut depth at the centroid of each dredge cut for each of the four drawdown scenarios is multiplied by the dissolved area of each dredge cut based on 2003 to 2019 dredge cut layouts.

The dissolved dredge cut surface area represents the area defined by combining individual dredge cuts from 2003 to 2019 into one complex shape and determining the area of that complex shape. Dredge cuts laid out for the time period 2003 through 2019 were used to do this. This is the time period for which complete GIS dredge cut data is available. There is a gap in data from 1999 to 2002 and though it would be possible to create additional data for the years prior to 1999, the team felt that 17 concurrent years (2003-2019) of dredging data was a large enough sample size to complete the analysis. That time period included representative variation in the magnitude, duration, and timing of high and low flow year, and variation in programmatic factors such as annual O&M budgets, dredge plant availability, placement site capacity, and the duration of the channel maintenance season. It is representative of contemporary dredging volumes which are higher than historical amounts.

To estimate the amount of additional dredging needed for each drawdown scenario, the decrease in LCP elevation at the dredge cut has to be determined since that equals the additional depth of dredging needed; and the dredge cut surface area has to be determined since that is the area that has to be dredged deeper. The product of these two gives the volume of additional dredging needed. The steps to do this are as follows:

Change in Dredging Depth

1. Assume that all the dredge cuts in the navigation pool will need additional dredging based on the amount of drawdown at each dredge cut. The drawdown at each dredge cut between the lock and dam and the control point in each pool will be based on the decrease in water surface elevation from routine water management to drawdown water management. Upstream of the control point, the maximum amount of drawdown will be limited to 0.5’ which is the control point constraint assumed for each navigation pool. The only exception to this is Pool 7, which is a dam point control pool and has no upstream CP. In Pool 7 the amount of drawdown throughout the pool is equal to that at Lock and Dam 7, with no control point constraint.

2. Determine the reduction in water surface elevation at the center river mile (centroid) of each composite dredge cut assuming a linear water surface profile between the dam and the control

point. For routine operations, use the tables that were already developed by water management and are used by channel maintenance personnel to determine the depth of dredging needed. For drawdowns use linear interpolation to determine the water surface elevation at each dredge cut for each of the 4 drawdown scenarios at the dam (0.5', 1.0', 1.5', 2.0') and assuming a 0.5' drawdown at the control point. For pools in Rock Island District, the reduction in water surface elevation at each dredge cut in each of the four drawdown scenarios was modelled under the same low-flow conditions used to estimate areas exposed by the drawdown. The modeled water surface elevations came from CWMS simulations for these pools.

3. Determine the difference (Δh) in water surface elevation between routine operations and the four drawdown scenarios

Dredge Cut Surface Area

4. For each pool go through the dredging database (2003 to 2019) and eliminate any dredging done outside of the navigation channel, including dredging needed for access to a placement site, non – navigation channel dredging, or any dredging that gets double counted because they are listed under two different dredging dredge cuts. Channels and Harbors staff were involved with this step. It makes sense not to include the access dredge cuts since dredging would be done prior to the drawdown so they wouldn't be any deeper than normal.

5. For each remaining dredge cut determine a composite dredge cut surface area that encompasses the footprint of all the individual dredging jobs that were done between 2003 and 2019 (dissolve is the term for this). The assumption here is that though individual dredge cut layouts shift from one year to the next, any area that was dredged between 2003 and 2019 probably has marginal depths and will have to be dredged during a drawdown. This assumption by itself may result in higher dredging estimates at individual cuts. However, we are also assuming that this is somewhat balanced by not including any channel areas that are not routinely dredged but have marginal depths that may require additional dredging.

Additional Dredging for Drawdowns

6. Multiply the composite dredge cut surface area by Δh to determine the additional amount of dredging volume needed at each dredge cut for each level of drawdown at the dam (0.5', 1.0', 1.5', 2.0') and assuming a 0.5' drawdown at the control point

7. Sum the additional dredge cut volume for all the dredge cuts to obtain the increase in dredging for the navigation pool.

Validating the Resulting Dredging Estimates

8. To validate this method the estimated drawdown dredging ratio, which is equal to the pool-wide dredging required to do a drawdown divided by the average annual pool-wide dredging during routine operations, was compared to dredging ratios observed during past drawdowns. This was done using the following equation.

Drawdown Dredging Ratio = (average annual dredging + additional dredging) / (average annual dredging)

9. A comparison of estimated to observed dredging ratios is given in the table below. Comparisons were made to observed dredging ratios in Pool 8 (2001) and Pool 5 (2005) and a detailed calculated cut by cut estimate done in Pool 3 for the North and Sturgeon Lake HREPs (2016). The ratios of drawdown dredging to average annual dredging were 3.4, 3.4, and 3.75 in Pools 8, 5, and 3 respectively for a 1.5' DD. The calculated cut by cut increases in Pool 3 (Cottrell 2016) for a 1.0' DD resulted in a ratio of 2.75. The results are shown in the table below.

Event	**Observed based on Dredging Records or Estimated based on Cut by Cut Layout**	**Estimated based on Above Method**
2001 drawdown dredging ratio, Observed in Pool 8, 1.5' DD at dam, 0.5' at C.P.	3.4 based on dredging records	4
2005 drawdown dredging ratio, Observed in Pool 5, 1.5' DD at dam, 0.5' at C.P.	3.4 based on dredging records	3.4
2016 drawdown dredging ratio, Cut by Cut estimate in Pool 3, 1.5' DD at Dam, 0.0' at C.P.	3.75, Estimated Cut by Cut Layout	4
2016 drawdown dredging ratio, Cut by Cut estimate Pool 3, 1.0' DD at Dam, 0.0' at C.P.	2.75, Estimated Cut by Cut Layout	3.1

The dredging ratios based on the methodology described above tend to be higher than those based on dredging records or the Pool 3 cut by cut analysis, however this is probably acceptable for this screening level analysis. It should be noted that the Pool 3 cut by cut analysis is based on the assumption of no drawdown allowed at the control point. The calculation of dredge cut surface area and amount of drawdown at each dredge cut can uniformly be applied to all dredge cuts, and therefore will be used without adjustment.

Definitions for dredging required methodology

1) Control Point (CP) – An upstream gage or location in a navigation pool used for regulating the pool if hinge point control operation is in effect.

2) Low Control Pool (LCP) – The lowest water level that can occur at any longitudinal position in a navigation pool for routine water management and for water management during a drawdown. Determined by linear interpolation between the downstream dam and the upstream control point for hinge pool operation.

3) LCP Routine – Lowest control pool for the existing operating plan.

4) LCP DD – Lowest control pool for the four DD scenarios (0.5', 1.0', 1.5', 2.0' at the downstream dam) and the maximum drawdown at the upstream control point (C.P.) of 0.5'. Upstream of the

control point, LCP DD is equal to the value at the control point. For dam point control, LCP throughout the pool was set equal to the water surface profile for the discharge exceeded 95% of the time in that pool based on CWMS simulations.

5) Drawdown (DD) – A decrease in water level from current minimum operating levels. At the downstream dam this will be 0.5', 1.0', 1.5', or 2.0' from the current LCP level that occurs during secondary control at the dam.

6) Control Point Constraint – The maximum amount of drawdown at the control point in each navigation pool. For this screening level effort this constraint will be 0.5' in the St. Paul District Pools that operate using hinge point control. This is the drawdown constraint at the control point that was used for both the 2001/02 drawdown in pool 8 and the 2005/06 drawdown in pool 5.

7) Dredge Cut Centroid – Approximate river mile of the longitudinal center of a dredge cut.

8) CutSqYards – GIS calculation of geographic 2D footprint of the dissolved dredge cut. Does not include overlaps.

9) Sum Cubic Yards – Total cubic yards of all events

10) Mean Cubic Yards – Sum Cubic Yards/Number of Events

11) Avg Annual Cubic Yards -– Sum Cubic Yards/17

12) Additional dredge cut depth – Difference between LCP existing and LCP for x.x ft DD at Dam

13) Additional Dredging for x.x ft at Dam (yd3) – CutSqYards * Dredge Cut DD for x.x ft at Dam

14) Drawdown Dredging = Average Annual Routine Dredging + Additional Dredging

15) Drawdown Dredging Ratio – (Avg Annual Cubic Yards + Additional Dredging)/Avg Annual Cubic Yard

Appendix E

Summary of costs and benefits associated with drawdowns in MVP and MVR from the NESP Report 53

Pool	Drawdown[1] Magnitude	Drawdown Success Rate	Acres Exposed	Incremental Acres Exposed	Dredging Required (yd^3)	Dredging Cost	Incremental Cost	Cost per Acre	Incremental Cost per Acre
5	1	95%	1,100	1,100	135,811	$643,175	$643,175	$585	$585
	2	81%	2,200	1,100	287,236	$1,365,093	$721,918	$620	$656
	3	55%	4,000	1,800	448,088	$2,137,217	$772,124	$534	$429
	4	38%	5,500	1,500	610,333	$2,935,132	$797,915	$534	$532
7	1	98%	1,206	1,206	0	$0	$0	$0	$0
	2	74%	2,331	1,125	215,000	$1,280,000	$1,280,000	$549	$1,138
	3	40%	3,385	1,054	475,000	$2,800,000	$1,520,000	$827	$1,442
8	1	74%	1,300	1,300	2,000	$88,000	$88,000	$68	$68
	2	50%	3,090	1,790	120,253	$475,000	$387,000	$154	$216
	3	33%	5,215	2,125	300,000	$1,185,000	$710,000	$227	$334
9	1	71%	4,751	4,751	0	$0	$0	$0	$0
	2	57%	6,932	2,181	75,000	$375,000	$375,000	$54	$172
	3	40%	9,497	2,565	165,000	$825,000	$450,000	$87	$175
11	1	91%	399	399	0	$0	$0	$0	$0
	2	86%	883	484	49,368	$399,400	$399,400	$452	$825
	3	86%	1,606	723	109,076	$762,441	$363,041	$475	$502
	4	64%	2,744	1,137	162,800	$976,800	$214,359	$356	$188
13	1	86%	1,560	1,560	35,200	$316,800	$316,800	$203	$203
	2	86%	2,822	1,262	131,032	$1,021,093	$704,293	$362	$558
	3	68%	4,519	1,697	229,768	$1,581,487	$560,394	$350	$330
	4	55%	6,821	2,303	325,600	$1,953,600	$372,113	$286	$162
16	1	55%	157	157	13,200	$118,800	$118,800	$757	$757
	2	55%	307	150	75,636	$601,121	$482,321	$1,955	$3,206
	3	50%	504	197	148,808	$1,031,148	$430,027	$2,045	$2,185
	4	23%	680	176	215,600	$1,293,600	$262,452	$1,901	$1,489
18	1	50%	484	484	26,400	$237,600	$237,600	$491	$491
	2	50%	761	277	133,848	$1,053,830	$816,230	$1,385	$2,949
	3	36%	1,054	293	247,500	$1,711,875	$658,045	$1,624	$2,243
	4	18%	1,305	251	356,400	$2,138,400	$426,525	$1,639	$1,702
19	1	100%	790	790	4,400	$39,600	$39,600	$50	$50
	2	100%	1,627	836	50,380	$403,500	$363,900	$248	$435
	3	100%	2,752	1,126	103,649	$721,547	$318,047	$262	$283
	4	100%	3,685	933	152,533	$915,198	$193,651	$248	$208

Appendix F - A description of the dabbling duck model variables and data sources utilized for the ecosystem benefits calculations

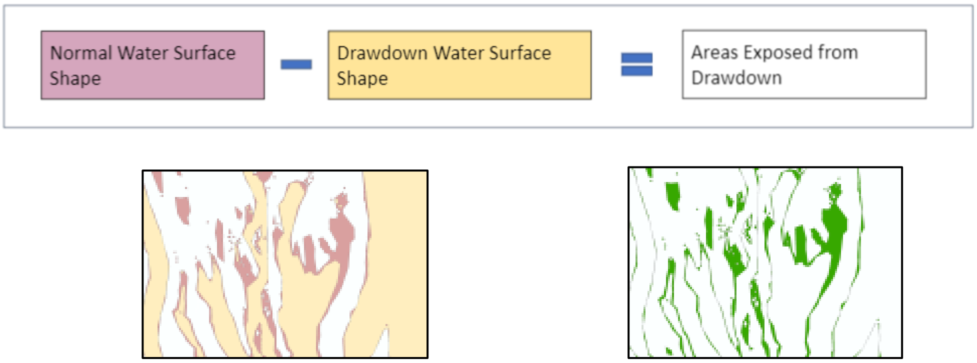
Variable Description	Data Source	Data Source (Phone Number or Hyperlink)
Distance to bottomland hardwoods, species composition, and water availability	U.S. Army Corps of Engineers St. Paul District and Rock Island District Forestry Datasets – Phase 1 and Phase 2	Contact the offices directly: Mississippi River Environmental Section (MVP), 651-290-5894 Mississippi River Project Office (MVR), 309-794-4528
Distance to cropland and cropland practices	USDA agricultural land use GIS layer	https://www.nass.usda.gov/Research_and_Science/Cropland/Release/
Water depth 4-18 inches in the fall	UMRR Long Term Resource Monitoring (LTRM) bathymetry data	https://www.sciencebase.gov/catalog/item/5 defac06e4b02caea0f4f0f2
Water depth less than 4 inches in the fall	UMRR LTRM bathymetry data	
Percent open water	UMRR LTRM bathymetry data	
Plant community diversity	UMRR LTRM aquatic vegetation data; UMRCC aquatic vegetation data; UMRR Land Cover Land Use (LCLU) data	https://umesc.usgs.gov/data_library/vegetation/srs/veg_srs_1_query.shtml https://www.umesc.usgs.gov/data_library/land_cover_use/2010_lcu_umesc.html
Important food plant coverage	UMRR LTRM aquatic vegetation data; UMRCC aquatic vegetation data; UMRR LCLU data	

Variable Description	Data Source	Data Source
Percent of area containing loafing structures	UMRR LCLU data	https://www.umesc.usgs.gov/data_library/land_cover_use/2010_lcu_umesc.html
Structure to provide thermal protection	UMRR LCLU data	
Disturbance in the fall	USFWS Sanctuary GIS layer	USFWS hunt data: https://fws.maps.arcgis.com/home/item.html?id=f59cbff6b219440a93f045ee583263dd Minnesota Data: https://gisdata.mn.gov/dataset/bdry-dnr-managed-areas and https://www.dnr.state.mn.us/hunting/tips/locations.html (hunting prohibited in state parks, state recreation areas, and state waysides) Wisconsin Data: https://data-wi-dnr.opendata.arcgis.com/datasets/dnr-managed-properties for property names; https://data-wi-dnr.opendata.arcgis.com/datasets/dnr-managed-land-parcels for parcels including hunting/fishing Iowa Data: https://open-iowa.opendata.arcgis.com/datasets/iowadnr::public-lands-used-for-conservation-and-recreation-in-iowa only used state property data Illinois Data: A FOIA request was submitted to DNR.FOIA@Illinois.gov for IL DNR properties that don't allow hunting Missouri Data: http://data-msdis.opendata.arcgis.com/datasets/mo-2020-missouri-department-of-conservation-lands and http://data-msdis.opendata.arcgis.com/datasets/mo-2020-missouri-department-of-natural-resources-land-boundaries (hunting prohibited in MO state Parks)
Visual barriers	UMRR LCLU data	https://www.umesc.usgs.gov/data_library/land_cover_use/2010_lcu_umesc.html

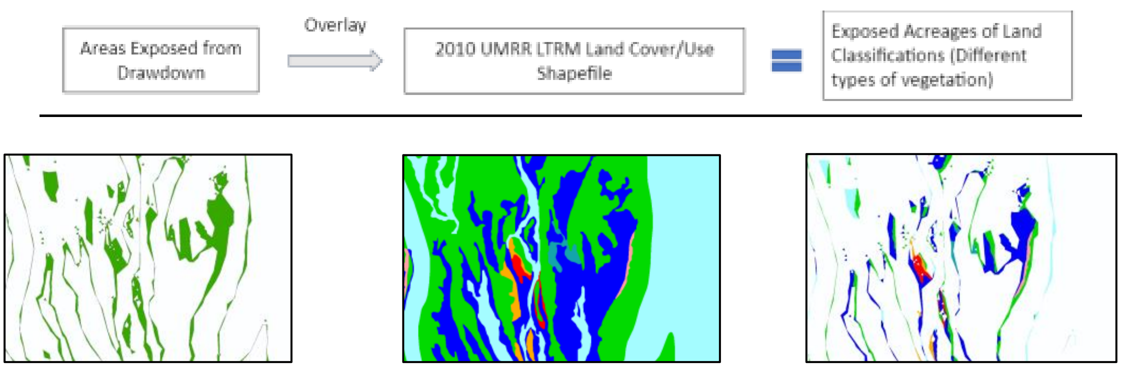
Appendix G - Methodology and GIS Techniques used to calculate Dabbling Duck Model scores

Determining exposed areas from drawdowns and calculating vegetation improvement

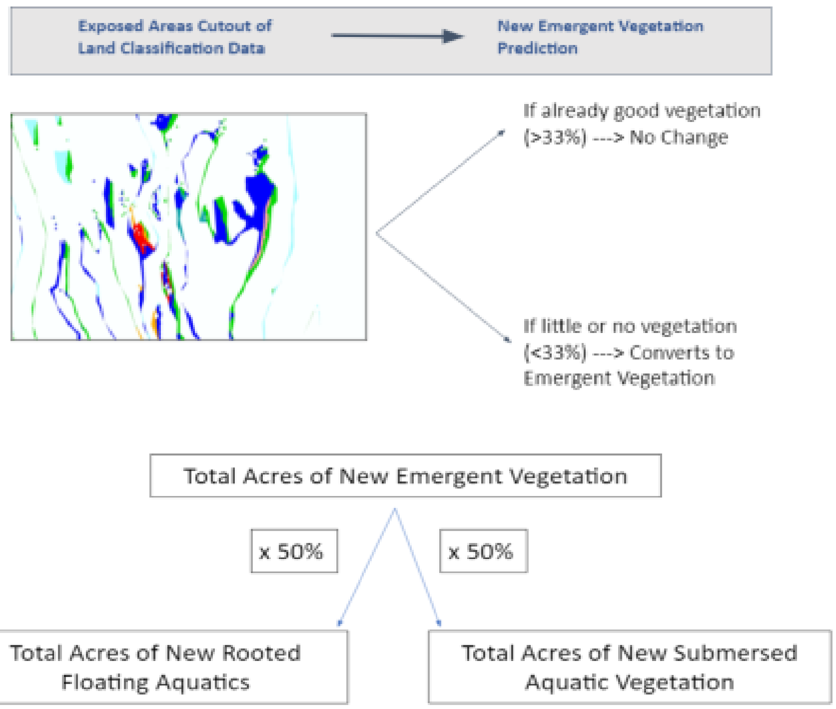
1. Using the ArcGIS tool "Erase," each drawdown water surface shape was subtracted from the normal water surface shape to produce a shapefile of the areas exposed from the drawdown.



2. The exposed areas shapefile was then used as the clipping input ("overlay") in the ArcGIS tool "Clip," with the pool's 2010 UMRR LTRM Land Cover/Land Use shapefile as the input feature. The output shapefile contains the exposed acreages of each land cover/land use classifications.

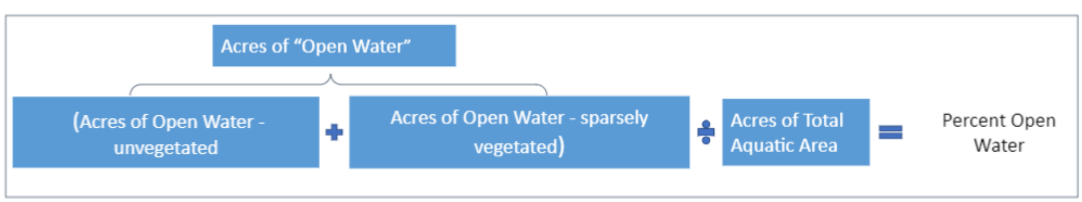


3. The exposed acreages were used to calculate predicted acres of new emergent vegetation, new rooted floating aquatics, and new submersed aquatic vegetation.

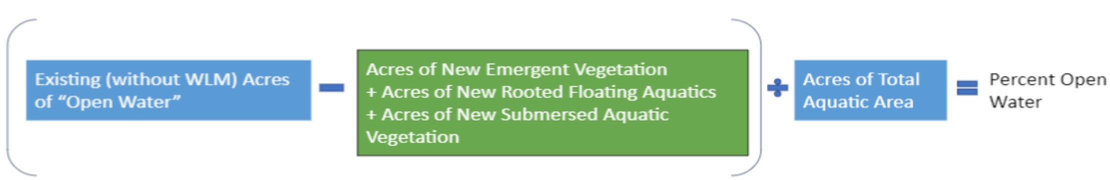


Variable 5, Percent Open Water

1. Future without WLM: Using a SQL query in the tool “Select by Attributes” in ArcGIS, the total acres of “Open Water” and total acres of “Aquatic Area” were pulled out of each pool’s 2010 UMRR LTRM Land Cover/Land Use data and used in the below equation to calculate the percent open water. The score for this variable is based on the percent open water.



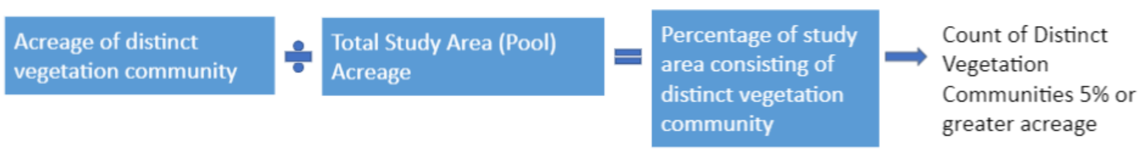
2. Future with WLM: to calculate the Percent Open Water with WLM, the total acres of new vegetation from the drawdown was subtracted from the “Future Without WLM” acres of Open Water, and divided again by the total acres of Aquatic Area.



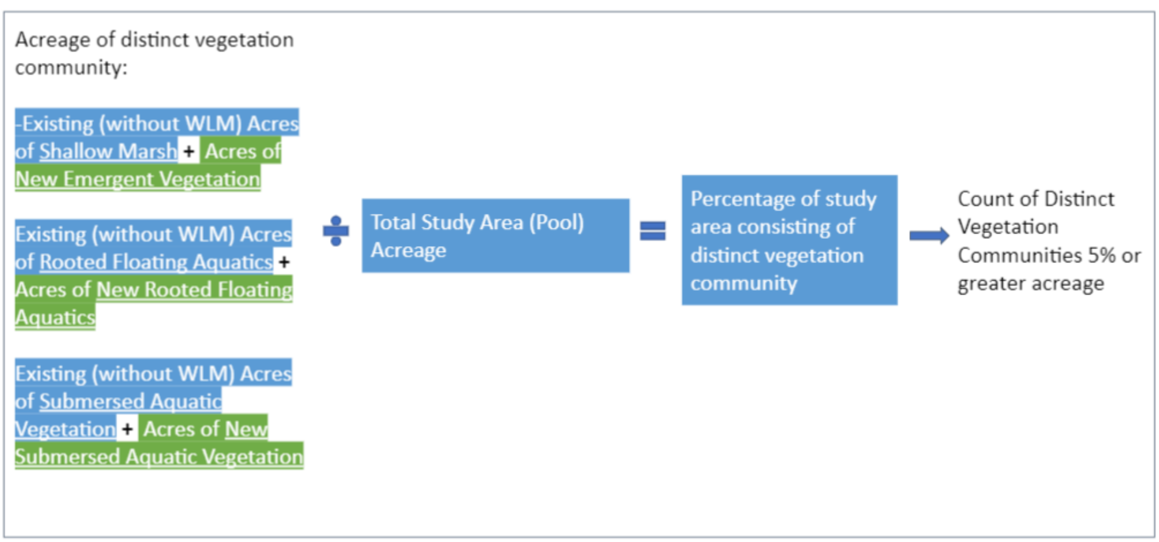
Variable 6, Plant Community Diversity

1. Future without WLM: Using a SQL query in the tool "Select by Attributes" in ArcGIS, the total acres of each of 7 specific vegetation communities and the total acres of the pool's study area were pulled out of each pool's 2010 UMRR LTRM Land Cover/Land Use data and used in the below equation to calculate the count of distinct plant communities. The acreage of each plant community is *individually* divided by the pool's total study area to come up with the percentage of the pool that the plant community takes up. Then the number of plant communities that take up 5% or more of the pool's area is counted, and the score for this variable is based on that count.

Plant Community
Class 7 Forest (A)
Class 7 Grass/Forbs (B)
Class 15 Wet Meadow (C)
Class 15 Shallow Marsh (D)
Class 15 Deep Marsh (E)
Class 15 Rooted Floating Aquatics (F)
Class 15 Submersed Aquatic Vegetation (G)



2. Future with WLM: to calculate the count of distinct of plant communities with WLM, the total acres of new vegetation from the drawdown is added to the "Future without WLM" acreages of specific plant communities, and then divided again individually by the pool's total study area to come up with the percentage of the study area that each plant community takes up.



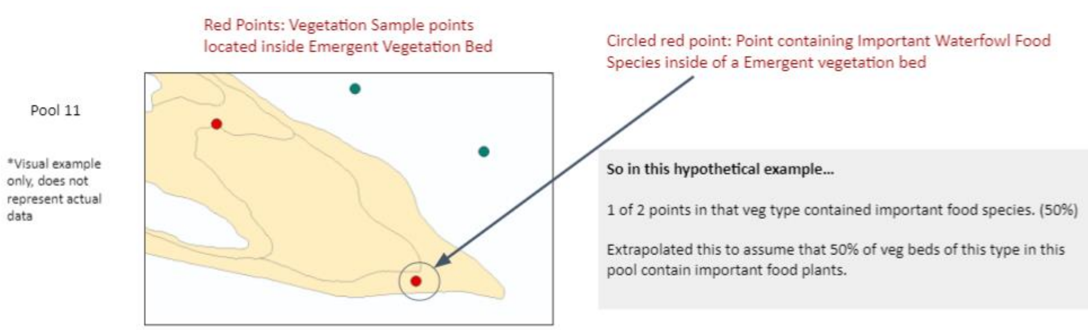
Variable 7, Important Food Plant Coverage

1. Future without WLM:

   a. Part 1 – Calculating the percentage of vegetation sample points that contain important waterfowl food species in each vegetation bed:

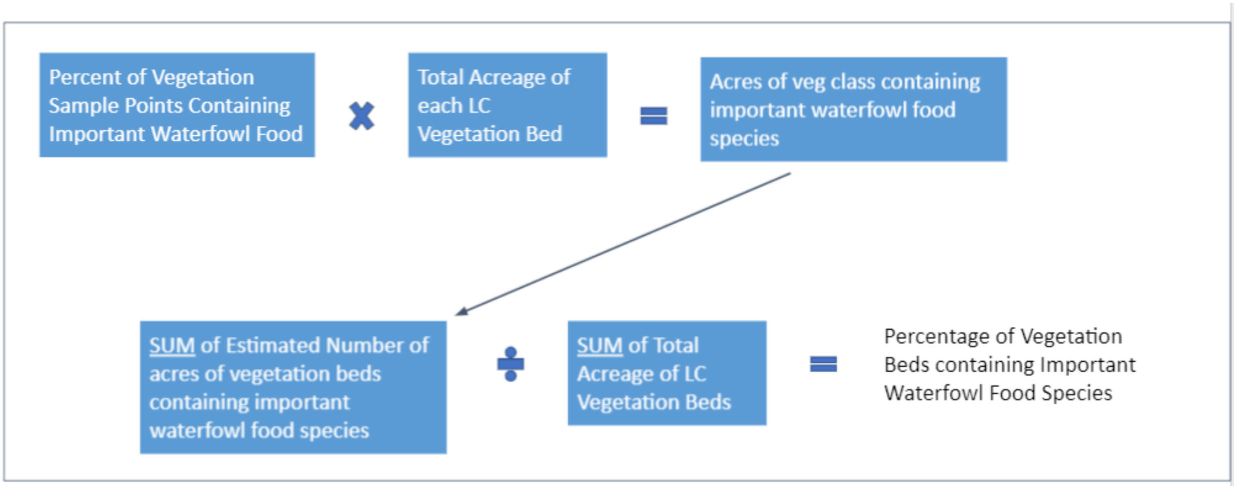
      First, a tabular data file of vegetation sample points for the pool was uploaded to ArcGIS and converted to a permanent point layer using the tools “Excel to Table,” “Make XY Event Layer,” and “Export Data” (to a feature class). These vegetation sample points include the plant species present within the sample. Then, specific vegetation beds (land classifications) from each pool’s 2010 UMRR LTRM Land Cover/Land Use data were pulled out and exported to a new polygon shapefile. Using the ArcGIS “Spatial Join,” a new point layer was created to append these specific vegetation bed types (land classification) to each vegetation sample point, but only where vegetation sample points were within the vegetation bed. This process was repeated for vegetation sample points within 20 feet of a vegetation bed, as this distance is close enough for the sample to be considered within the bed. The 2 sets of spatial join data were exported to tabular format and tallied to count (1) all sample points inside or within 20 feet of a vegetation bed and (2) how many of these sample points include important waterfowl food plant species. These counts were then used in the equation below:

Count of Vegetation Sample Points Containing any Important Waterfowl Food Plant Species that are located inside or within 20 feet of LC Vegetation Bed ÷ Count of All Vegetation Sample Points located inside or within 20 feet of LC Vegetation Bed = Percent of Vegetation Sample Points Containing Important Waterfowl Food Plant Species in each LC Vegetation Bed

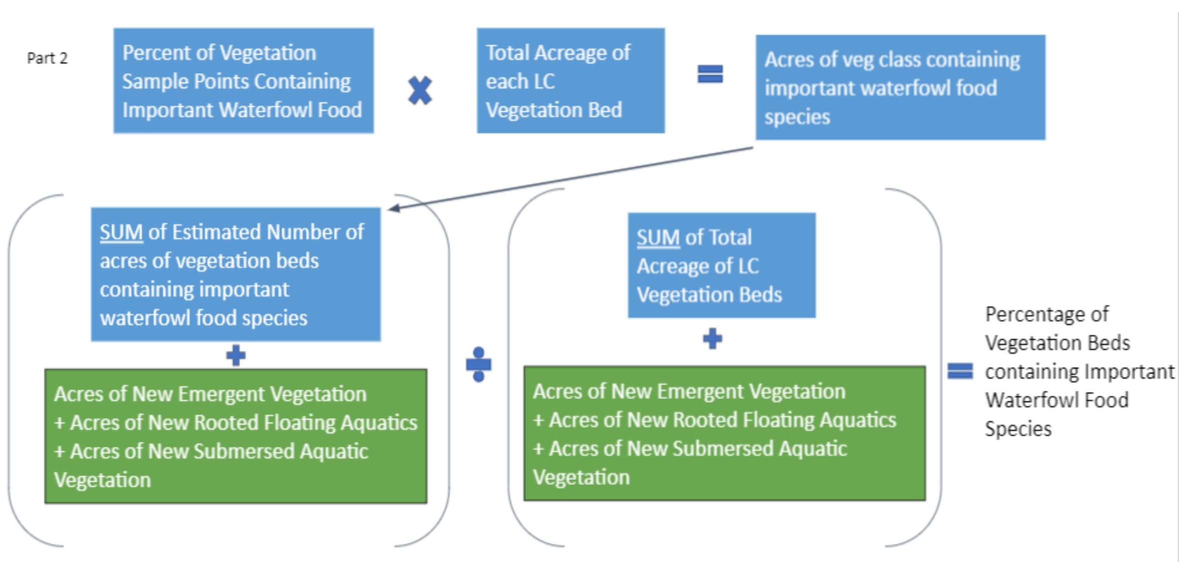


b. Part 2 – Calculating the percentage of vegetation beds containing important waterfowl food species (important food plant coverage):

The percentage of vegetation sample points that contain important waterfowl food species for each vegetation bed (calculated above in Part 1), along with the total acreage of each vegetation bed is used in the below equation, and the score for this variable is based on the result.



2. Future with WLM: to calculate the percentage of vegetation beds containing important waterfowl food species (important food plant coverage) with WLM, the total acres of new vegetation from the drawdown is added to (1) the sum of acres of vegetation beds containing important waterfowl food species and (2) the sum of the total acres of each vegetation bed in the pool.



The following other variables of the Dabbling Duck Model were only calculated and scored based on Future without WLM Conditions.

Variable 1, Distance to Bottomland Hardwoods

First, the ArcGIS tool "Buffer" was used to create a one mile buffer polygon shapefile around and including the pool study area. Next, 2 shapefiles representing areas with greater than 25% oak and areas with less than 25% oak were used in the ArcGIS tool "Clip" as the clipping input, and the one mile buffer shapefile as the input feature to create 2 separate shapefiles. These resultant shapefiles were opened to see if either or both contained data, and scored accordingly.

Variable 2, Distance to cropland and cropland practices

First, the ArcGIS tool "Buffer" was used to create a 0.25 mile and 1 mile buffer polygon shapefile around and including the pool study area. Next, the USDA cover raster was used to pull out areas of certain crops and output into a polygon shapefile. This cropland polygon shapefile was clipped (ArcGIS tool "Clip") by both the 0.25 mile buffer shapefile and 1 mile buffer shapefile to output 2 new shapefiles. Finally, acreage data was generated from these 2 shapefiles and used to calculate the percentage of cropland within 1 mile and 0.25 miles, which were used to determine the model score.

Variable 3, Water Depth 4-18 Inches in fall and Variable 4, Water Depths < 4 Inches in fall

First, the bathymetric raster data was converted to inches using the tools "Build Raster Attribute Table," "Add DepthClass Field," and "Convert Depths to Inches." Next, the ArcGIS Spatial Analyst Extension tool "Reclassify" was used to classify the rasters based on the following classifications:

Water Depth in Inches	**Class number**
0 – 3.9999	1
4 – 18	2
18.0001 – 99999	3

For Variable 3, the class 2 (4-18 inches) cell count was divided by the total cell count to get the percentage of cells that are 4-18 inches in the fall, and then scored accordingly. For scoring Variable 4, the class 1 (0 - 3.9999 inches) cell count was used instead.

Variable 8, Percent of area containing loafing structures

First, the ArcGIS tool "Select" was used to select specific "Class 31" land cover/land use categories that represent areas that could serve as loafing structures from each pool's 2010 UMRR LTRM Land Cover/Land Use data. The total acreage of these areas was then divided by the total pool study area acreage to get the percentage, which was then used to score the model variable.

Variable 9, Structure to Provide Thermal Protection

First, the ArcGIS tool "Select" was used to select the values "Marsh" and "Grass/Forbs" from the "Class 7" and "Class 15" land cover/land use categories (from each pool's 2010 UMRR LTRM Land Cover/Land Use data) that can serve as structures to provide thermal protection and output to a new shapefile. The values within this new shapefile were dissolved together using the ArcGIS tool "Dissolve," and then the "Select" tool used again to select the beds over 0.0247 acres (large beds) into another shapefile. Then the “Select” tool was used a third time to select the value “Forest” from the “Class 7” land cover/land use category that can serve as structures to provide thermal protection and output to a new shapefile. Finally, the large vegetation beds shapefile and tree or shrub shapefile were merged together with the ArcGIS tool “Merge” and the total acreage calculated. This total acreage of thermal protection areas was then divided by the total acreage of the study area, and this percentage was used to score the variable.

<u>Variable 10, Disturbance in the fall</u>

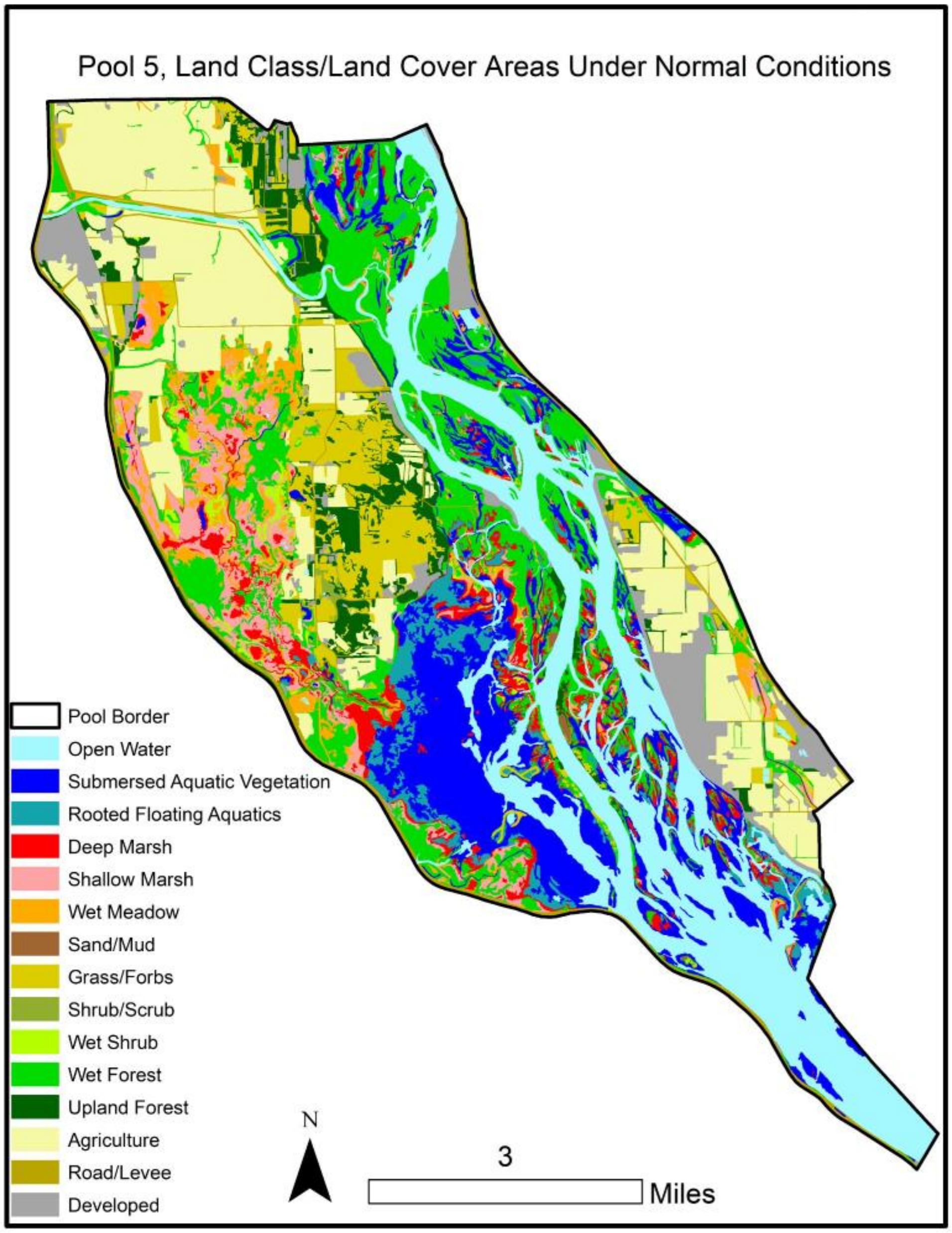
First, USFWS and state public lands layers were merged with the ArcGIS tool “Merge” into one public lands shapefile. Then the public lands shapefile was clipped (ArcGIS tool “Clip) by the pool’s study area to narrow down the public land into a new shapefile representing the pool’s study area. Each feature (polygon) within the shapefile was given a suitability index based on 4 different criteria: 1) Closed to hunting and no other human activity occurs (best), 2) Closed to hunting, human activity during migration is minimal or access restricted, 3) Closed to hunting but considerable human activity during migration, and 4) Open to hunting, access unrestricted (worst). Then a weighted average of the suitability index scores was calculated based on the acreages, and summed to determine the final score of the variable.

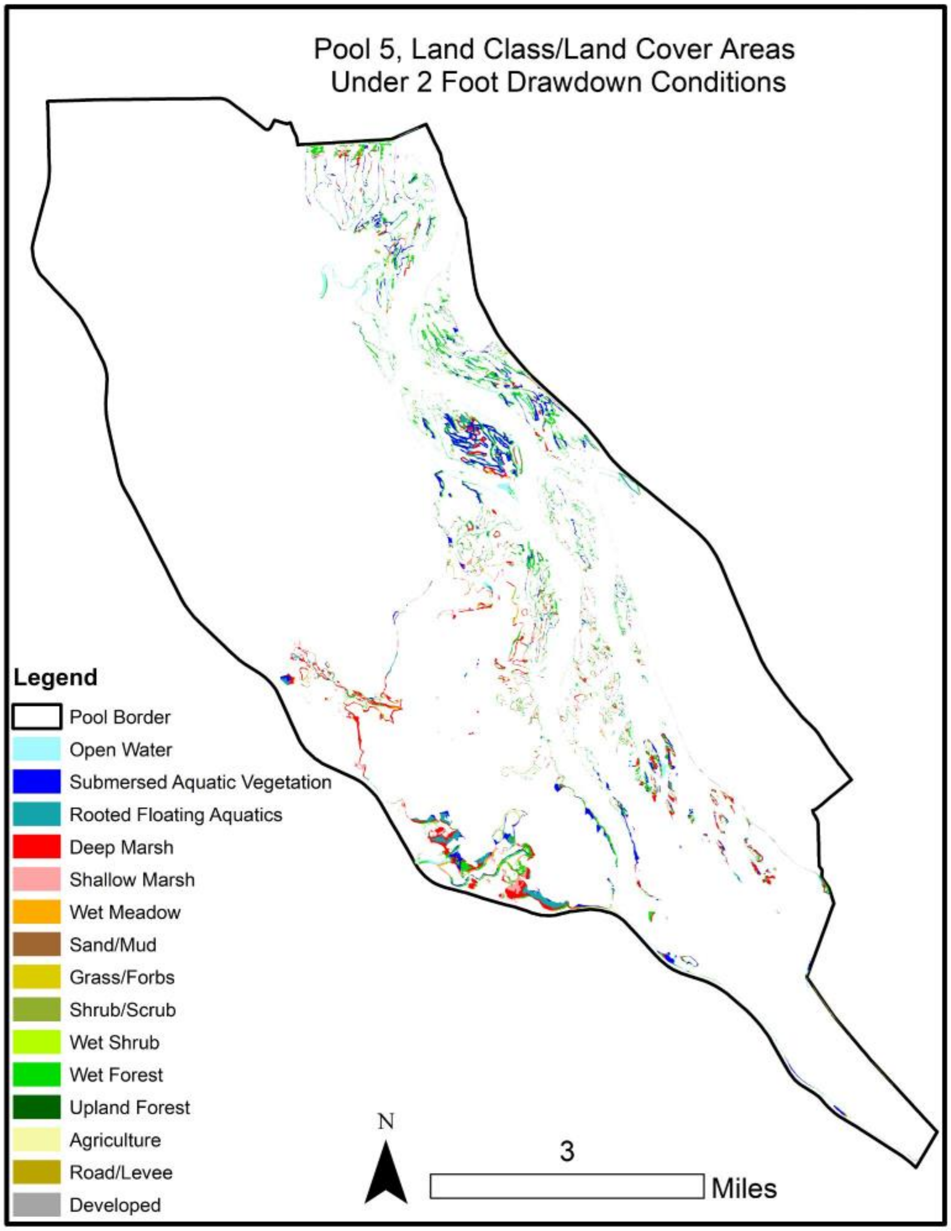
<u>Variable 11, Visual Barriers</u>

First, a Python script was run to assign a Suitability Index score based on the value from the attribute “Cover_C” from each pool’s 2010 UMRR LTRM Land Cover/Land Use data. Then, a weighted suitability index is calculated based on the percentage of each density category A, B, C, or D in the entire pool study area (based on acres), and then the weighted suitability index scores summed to produce a final suitability index, which is used to score the variable.

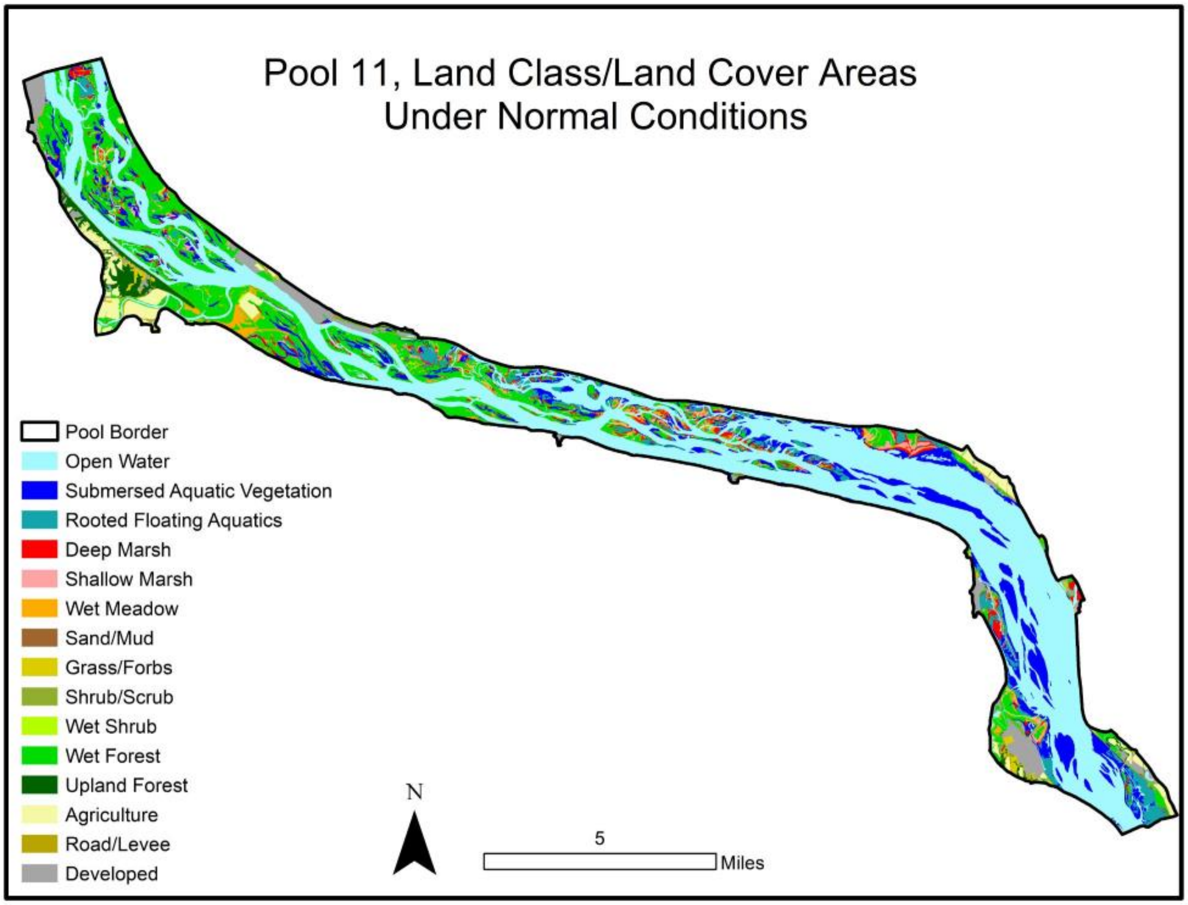
Appendix H - Maps of Exposed Areas from Drawdowns for UMR Pools 5 and 11

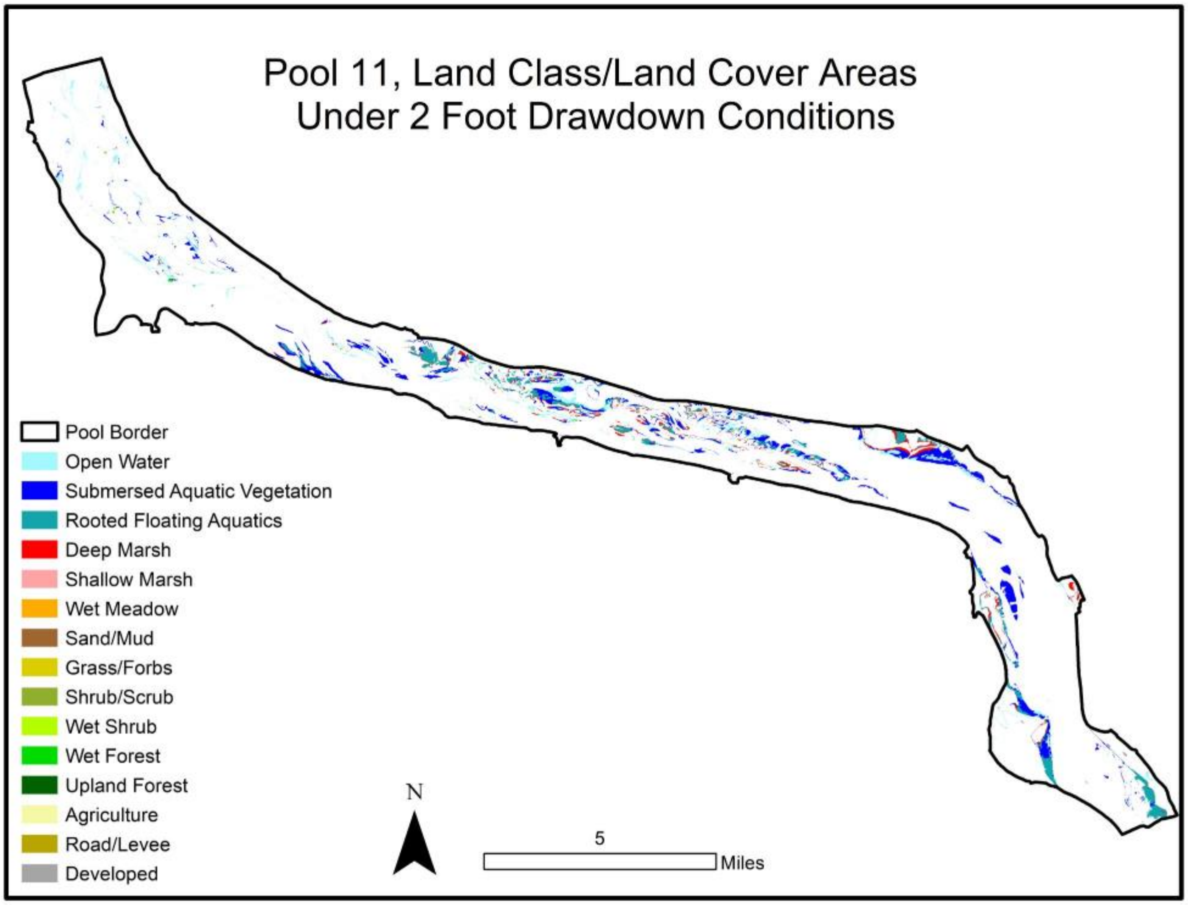
Each map indicates either the pool's land cover under regular or "normal" conditions and the subsequent map represents the land cover areas that are exposed under drawdown conditions.





Pool 5, Land Class/Land Cover Areas
Under 2 Foot Drawdown Conditions
Legend
Pool Border
Open Water
Submersed Aquatic Vegetation
Rooted Floating Aquatics
Deep Marsh
Shallow Marsh
Wet Meadow
Sand/Mud
Grass/Forbs
Shrub/Scrub
Wet Shrub
Wet Forest
Upland Forest
Agriculture
Road/Levee
Developed
N
3
Miles


Pool 11, Land Class/Land Cover Areas
Under Normal Conditions
Pool Border
Open Water
Submersed Aquatic Vegetation
Rooted Floating Aquatics
Deep Marsh
Shallow Marsh
Wet Meadow
Sand/Mud
Grass/Forbs
Shrub/Scrub
Wet Shrub
Wet Forest
Upland Forest
Agriculture
Road/Levee
Developed
N
5
Miles


Pool 11, Land Class/Land Cover Areas
Under 2 Foot Drawdown Conditions
Pool Border
Open Water
Submersed Aquatic Vegetation
Rooted Floating Aquatics
Deep Marsh
Shallow Marsh
Wet Meadow
Sand/Mud
Grass/Forbs
Shrub/Scrub
Wet Shrub
Wet Forest
Upland Forest
Agriculture
Road/Levee
Developed
N
5
Miles

Appendix I – Dabbling Duck Migration Model HSI Results and HEP Analysis Tables for All Pools Evaluated

St. Paul District Pools - Full Results of HEP Modeling with Dabbling Duck Migration Model for the Upper Mississippi River (Devendorf 2013)

			Pool 2					Pool 3				
			Existing	0.5	1.0	1.5	2.0	Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables												
1	Distance to bottomland hardwoods	max 5	1	1	1	1	1	5	5	5	5	5
2	Distance to Cropland	max 5	1	1	1	1	1	3	3	3	3	3
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1	1	1	1	1	1
5	Percent Open Water	max 10	1	5	7	7	7	5	7	7	7	7
6	Plant Community Diversity	max 10	1	4	4	4	4	6	6	6	6	6
7	Important food plant coverage	max 10	0.5	6	6	8	8	6	6	6	6	6
8	Percent Area w/ Loafing Structures	max 5	4	4	4	4	4	5	5	5	5	5
9	Thermal Protection	max 5	3	3	3	3	3	5	5	5	5	5
10	Disturbance in the Fall	max 10	4	4	4	4	4	1	1	1	1	1
11	Visual Barriers	max 5	2	2	2	2	2	4	4	4	4	4
	TOTAL	max 85	19.5	32	34	36	36	42	44	44	44	44
	HSI	total/85	0.23	0.38	0.40	0.42	0.42	0.49	0.52	0.52	0.52	0.52
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window												
	Acres		25332	25332	25332	25332	25332	23801	23801	23801	23801	23801
	Period of Evaluation (years)		50	50	50	50	50	50	50	50	50	50
	Average Annual Habitat Units (AAHU)		5811.5	9536.8	10132.8	10728.8	10728.8	11760.5	12320.5	12320.5	12320.5	12320.5
	AAHUs annualized across 50 years		-	6370.3	6459.7	6549.1	6549.1	-	11844.5	11844.5	11844.5	11844.5
	AAHU Gain		-	558.8	648.2	737.6	737.6	-	84.0	84.0	84.0	84.0
Cost/Benefit Comparison												
	Total AAHUs		-	558.8	648.2	737.6	737.6	-	84.	84.	84.	84.
	Estimated Dredging Costs		-	$ 1,350,000	$ 2,070,000	$ 2,800,000	$ 3,520,000	-	$ 1,750,000	$ 3,030,000	$ 4,300,000	$ 7,000,000
	Annualized Cost (2.5% discount rate)		-	$ 48,000	$ 73,000	$ 99,000	$ 124,000	-	$ 62,000	$ 107,000	$ 152,000	$ 247,000
	Cost per Average Annual Habitat Unit		-	$ 85	$ 113	$ 134	$ 168	-	$ 735	$ 1,272	$ 1,805	$ 2,938

			Pool 5					Pool 5A					Pool 6				
			Existing	0.5	1.0	1.5	2.0	Existing	0.5	1.0	1.5	2.0	Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables																	
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3
2	Distance to Cropland	max 5	3	3	3	3	3	1	1	1	1	1	2	2	2	2	2
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	Percent Open Water	max 10	10	10	10	10	10	10	10	10	10	10	7	10	10	10	10
6	Plant Community Diversity	max 10	4	4	4	4	6	6	6	6	6	6	4	6	6	6	6
7	Important food plant coverage	max 10	8	8	8	8	8	10	10	10	10	10	10	10	10	10	10
8	Percent Area w/ Loafing Structures	max 5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
9	Thermal Protection	max 5	4	4	4	4	4	5	5	5	5	5	4	4	4	4	4
10	Disturbance in the Fall	max 10	3	3	3	3	3	2	2	2	2	2	1	1	1	1	1
11	Visual Barriers	max 5	3	3	3	3	3	4	4	4	4	4	3	3	3	3	3
	TOTAL	max 85	47	47	47	47	49	50	50	50	50	50	41	46	46	46	46
	HSI	total/85	0.55	0.55	0.55	0.55	0.58	0.59	0.59	0.59	0.59	0.59	0.48	0.54	0.54	0.54	0.54
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window																	
	Acres		16361	16361	16361	16361	16361	45316	45316	45316	45316	45316	45316	45316	45316	45316	45316
	Period of Evaluation (years)		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Average Annual Habitat Units (AAHU)		9046.7	9046.7	9046.7	9046.7	9431.6	26656.5	26656.5	26656.5	26656.5	26656.5	21858.3	24524.0	24524.0	24524.0	24524.0
	AAHUs annualized across 50 years		-	9046.7	9046.7	9046.7	9104.4	-	26656.5	26656.5	26656.5	26656.5	-	22258.2	22258.2	22258.2	22258.2
	AAHU Gain		-	0.0	0.0	0.0	57.7	-	0.0	0.0	0.0	0.0	-	399.8	399.8	399.8	399.8
Cost/Benefit Comparison																	
	Total AAHUs		-	0.	0.	0.	57.7	-	0.	0.	0.	0.	-	399.8	399.8	399.8	399.8
	Estimated Dredging Costs		-	$ 3,760,000	$ 4,840,000	$ 5,940,000	$ 7,040,000	-	$ 380,000	$ 630,000	$ 880,000	$ 1,130,000	-	$ 1,340,000	$ 1,890,000	$ 2,420,000	$ 2,960,000
	Annualized Cost (2.5% discount rate)		-	$ 133,000	$ 171,000	$ 209,000	$ 248,000	-	$ 13,000	$ 22,000	$ 31,000	$ 40,000	-	$ 47,000	$ 67,000	$ 85,000	$ 104,000
	Cost per Average Annual Habitat Unit		-	N/A	N/A	N/A	$ 4,299	-	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	-	$ 118	$ 167	$ 213	$ 261

			Pool 7					Pool 8				
			Existing	0.5	1.0	1.5	2.0	Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables												
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5	5	5	5	5	5
2	Distance to Cropland	max 5	3	3	3	3	3	1	1	1	1	1
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1	1	1	1	1	1
5	Percent Open Water	max 10	7	7	7	10	10	7	10	10	10	10
6	Plant Community Diversity	max 10	4	4	4	4	4	6	6	6	10	10
7	Important food plant coverage	max 10	10	10	10	10	10	10	10	10	10	10
8	Percent Area w/ Loafing Structures	max 5	5	5	5	5	5	5	5	5	5	5
9	Thermal Protection	max 5	4	4	4	4	4	3	3	3	3	3
10	Disturbance in the Fall	max 10	3	3	3	3	3	3	3	3	3	3
11	Visual Barriers	max 5	3	3	3	3	3	3	3	3	3	3
	TOTAL	max 85	46	46	46	49	49	45	48	48	52	52
	HSI	total/85	0.54	0.54	0.54	0.58	0.58	0.53	0.56	0.56	0.61	0.61
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window												
	Acres		45316	45316	45316	45316	45316	45316	45316	45316	45316	45316
	Period of Evaluation (years)		50	50	50	50	50	50	50	50	50	50
	Average Annual Habitat Units (AAHU)		24524.0	24524.0	24524.0	26123.3	26123.3	23990.8	25590.2	25590.2	27722.7	27722.7
	AAHUs annualized across 50 years		-	24524.0	24524.0	24763.9	24763.9	-	24230.7	24230.7	24550.6	24550.6
	AAHU Gain		-	0.0	0.0	239.9	239.9	-	239.9	239.9	559.8	559.8
Cost/Benefit Comparison												
	Total AAHUs		-	0.	0.	239.9	239.9	-	239.9	239.9	559.8	559.8
	Estimated Dredging Costs		-	$ 1,260,000	$ 2,540,000	$ 3,810,000	$ 5,070,000	-	$ 1,880,000	$ 2,660,000	$ 3,440,000	$ 5,240,000
	Annualized Cost (2.5% discount rate)		-	$ 44,000	$ 90,000	$ 134,000	$ 179,000	-	$ 66,000	$ 94,000	$ 121,000	$ 185,000
	Cost per Average Annual Habitat Unit		-	#DIV/0!	#DIV/0!	$ 560	$ 745	-	$ 276	$ 391	$ 217	$ 330

			Pool 9					Pool 10				
			Existing	0.5	1.0	1.5	2.0	Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables												
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5	5	5	5	5	5
2	Distance to Cropland	max 5	1	1	1	1	1	1	1	1	1	1
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1	1	1	1	1	1
5	Percent Open Water	max 10	10	10	10	10	10	7	7	7	7	7
6	Plant Community Diversity	max 10	4	6	6	6	6	4	4	4	4	4
7	Important food plant coverage	max 10	10	10	10	10	10	8	8	8	8	8
8	Percent Area w/ Loafing Structures	max 5	5	5	5	5	5	5	5	5	5	5
9	Thermal Protection	max 5	4	4	4	4	4	3	3	3	3	3
10	Disturbance in the Fall	max 10	2	2	2	2	2	2	2	2	2	2
11	Visual Barriers	max 5	4	4	4	4	4	3	3	3	3	3
	TOTAL	max 85	47	49	49	49	49	40	40	40	40	40
	HSI	total/85	0.55	0.58	0.58	0.58	0.58	0.47	0.47	0.47	0.47	0.47
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window												
	Acres		45316	45316	45316	45316	45316	16361	16361	16361	16361	16361
	Period of Evaluation (years)		50	50	50	50	50	50	50	50	50	50
	Average Annual Habitat Units (AAHU)		25057.1	26123.3	26123.3	26123.3	26123.3	7699.3	7699.3	7699.3	7699.3	7699.3
	AAHUs annualized across 50 years		-	25217.0	25217.0	25217.0	25217.0	-	7699.3	7699.3	7699.3	7699.3
	AAHU Gain		-	159.9	159.9	159.9	159.9	-	0.0	0.0	0.0	0.0
Cost/Benefit Comparison												
	Total AAHUs		-	159.9	159.9	159.9	159.9	-	0.	0.	0.	0.
	Estimated Dredging Costs		-	$ 730,000	$ 750,000	$ 770,000	$ 790,000	-	$ 2,150,000	$ 3,180,000	$ 4,180,000	$ 5,180,000
	Annualized Cost (2.5% discount rate)		-	$ 26,000	$ 26,000	$ 27,000	$ 28,000	-	$ 76,000	$ 112,000	$ 147,000	$ 183,000
	Cost per Average Annual Habitat Unit		-	$ 161	$ 165	$ 170	$ 174	-	N/A	N/A	N/A	N/A

Rock Island District Pools - Full Results of HEP Modeling with Dabbling Duck Migration Model for the Upper Mississippi River (Devendorf 2013)

Pool 11

			Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables							
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5
2	Distance to Cropland	max 5	2	2	2	2	2
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1
5	Percent Open Water	max 10	5	5	7	7	7
6	Plant Community Diversity	max 10	4	4	4	4	6
7	Important food plant coverage	max 10	8	8	10	10	10
8	Percent Area w/ Loafing Structures	max 5	4	4	4	4	4
9	Thermal Protection	max 5	3	3	3	3	3
10	Disturbance in the Fall	max 10	2	2	2	2	2
11	Visual Barriers	max 5	3	3	3	3	3
	TOTAL	max 85	38	38	42	42	44
	HSI	total/85	0.45	0.45	0.49	0.49	0.52
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window							
	Acres		33389	33389	33389	33389	33389
	Period of Evaluation (years)		50	50	50	50	50
	Average Annual Habitat Units (AAHU)		14926.8	14926.8	16498.1	16498.1	17283.7
	AAHUs annualized across 50 years		-	14926.8	15162.5	15162.5	15280.4
	AAHU Gain		-	0.0	235.7	235.7	353.5
Cost/Benefit Comparison							
	Total AAHUs		-	0.	235.7	235.7	353.5
	Estimated Dredging Costs		-	$ 380,000	$ 1,300,000	$ 2,300,000	$ 3,240,000
	Annualized Cost (2.5% discount rate)		-	$ 13,000	$ 46,000	$ 81,000	$ 114,000
	Cost per Average Annual Habitat Unit		-	#DIV/0!	$ 194	$ 344	$ 323

Pool 12

			Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables							
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5
2	Distance to Cropland	max 5	1	1	1	1	1
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1
5	Percent Open Water	max 10	5	7	7	7	7
6	Plant Community Diversity	max 10	4	4	4	4	4
7	Important food plant coverage	max 10	10	10	10	10	10
8	Percent Area w/ Loafing Structures	max 5	5	5	5	5	5
9	Thermal Protection	max 5	3	3	3	3	3
10	Disturbance in the Fall	max 10	1	1	1	1	1
11	Visual Barriers	max 5	3	3	3	3	3
	TOTAL	max 85	39	41	41	41	41
	HSI	total/85	0.46	0.48	0.48	0.48	0.48
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window							
	Acres		22038	22038	22038	22038	22038
	Period of Evaluation (years)		50	50	50	50	50
	Average Annual Habitat Units (AAHU)		10111.6	10630.1	10630.1	10630.1	10630.1
	AAHUs annualized across 50 years		-	10189.3	10189.3	10189.3	10189.3
	AAHU Gain		-	77.8	77.8	77.8	77.8
Cost/Benefit Comparison							
	Total AAHUs		-	77.8	77.8	77.8	77.8
	Estimated Dredging Costs		-	$ 210,000	$ 460,000	$ 710,000	$ 960,000
	Annualized Cost (2.5% discount rate)		-	$ 7,000	$ 16,000	$ 25,000	$ 34,000
	Cost per Average Annual Habitat Unit		-	$ 95	$ 209	$ 322	$ 435

Pool 13

			Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables							
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5
2	Distance to Cropland	max 5	3	3	3	3	3
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1
5	Percent Open Water	max 10	7	10	10	10	10
6	Plant Community Diversity	max 10	4	4	4	4	4
7	Important food plant coverage	max 10	10	10	10	10	10
8	Percent Area w/ Loafing Structures	max 5	4	4	4	4	4
9	Thermal Protection	max 5	3	3	3	3	3
10	Disturbance in the Fall	max 10	2	2	2	2	2
11	Visual Barriers	max 5	3	3	3	3	3
	TOTAL	max 85	43	46	46	46	46
	HSI	total/85	0.51	0.54	0.54	0.54	0.54
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window							
	Acres		84061	84061	84061	84061	84061
	Period of Evaluation (years)		50	50	50	50	50
	Average Annual Habitat Units (AAHU)		42525.0	45491.8	45491.8	45491.8	45491.8
	AAHUs annualized across 50 years		-	42970.0	42970.0	42970.0	42970.0
	AAHU Gain		-	445.0	445.0	445.0	445.0
Cost/Benefit Comparison							
	Total AAHUs		-	445.	445.	445.	445.
	Estimated Dredging Costs		-	$ 530,000	$ 1,510,000	$ 2,470,000	$ 3,550,000
	Annualized Cost (2.5% discount rate)		-	$ 19,000	$ 53,000	$ 87,000	$ 125,000
	Cost per Average Annual Habitat Unit		-	$ 42	$ 120	$ 196	$ 281

Pool 16

			Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables							
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5
2	Distance to Cropland	max 5	2	2	2	2	2
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1
5	Percent Open Water	max 10	1	5	5	5	7
6	Plant Community Diversity	max 10	1	1	1	1	1
7	Important food plant coverage	max 10	0.5	3	4	8	8
8	Percent Area w/ Loafing Structures	max 5	4	4	4	4	4
9	Thermal Protection	max 5	3	3	3	3	3
10	Disturbance in the Fall	max 10	2	2	2	2	2
11	Visual Barriers	max 5	2	2	2	2	2
	TOTAL	max 85	22.5	29	30	34	36
	HSI	total/85	0.26	0.34	0.35	0.40	0.42
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window							
	Acres		34524	34524	34524	34524	34524
	Period of Evaluation (years)		50	50	50	50	50
	Average Annual Habitat Units (AAHU)		9138.7	11778.8	12184.9	13809.6	14621.9
	AAHUs annualized across 50 years		-	9534.7	9595.6	9839.3	9961.2
	AAHU Gain		-	396.0	456.9	700.6	822.5
Cost/Benefit Comparison							
	Total AAHUs		-	396.	456.9	700.6	822.5
	Estimated Dredging Costs		-	$ 1,450,000	$ 2,570,000	$ 3,370,000	$ 3,990,000
	Annualized Cost (2.5% discount rate)		-	$ 51,000	$ 91,000	$ 119,000	$ 141,000
	Cost per Average Annual Habitat Unit		-	$ 129	$ 198	$ 170	$ 171

Pool 18

			Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables							
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5
2	Distance to Cropland	max 5	5	5	5	5	5
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1
5	Percent Open Water	max 10	1	5	5	5	7
6	Plant Community Diversity	max 10	1	1	1	1	1
7	Important food plant coverage	max 10	0.5	2	2	6	6
8	Percent Area w/ Loafing Structures	max 5	4	4	4	4	4
9	Thermal Protection	max 5	3	3	3	3	3
10	Disturbance in the Fall	max 10	3	3	3	3	3
11	Visual Barriers	max 5	2	2	2	2	2
	TOTAL	max 85	26.5	32	32	36	38
	HSI	total/85	0.31	0.38	0.38	0.42	0.45
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window							
	Acres		126489	126489	126489	126489	126489
	Period of Evaluation (years)		50	50	50	50	50
	Average Annual Habitat Units (AAHU)		39434.8	47619.4	47619.4	53571.8	56548.0
	AAHUs annualized across 50 years		-	40662.5	40662.5	41555.4	42001.8
	AAHU Gain		-	1227.7	1227.7	2120.6	2567.0
Cost/Benefit Comparison							
	Total AAHUs		-	1227.7	1227.7	2120.6	2567.
	Estimated Dredging Costs		-	$ 390,000	$ 1,330,000	$ 2,580,000	$ 3,790,000
	Annualized Cost (2.5% discount rate)		-	$ 14,000	$ 47,000	$ 91,000	$ 134,000
	Cost per Average Annual Habitat Unit		-	$ 11	$ 38	$ 43	$ 52

Pool 19

			Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables							
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5
2	Distance to Cropland	max 5	4	4	4	4	4
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1
5	Percent Open Water	max 10	1	5	5	5	7
6	Plant Community Diversity	max 10	1	1	1	1	1
7	Important food plant coverage	max 10	3	3	4	8	8
8	Percent Area w/ Loafing Structures	max 5	4	4	4	4	4
9	Thermal Protection	max 5	2	2	2	2	2
10	Disturbance in the Fall	max 10	2	2	2	2	2
11	Visual Barriers	max 5	2	2	2	2	2
	TOTAL	max 85	26	30	31	35	37
	HSI	total/85	0.31	0.35	0.36	0.41	0.44
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window							
	Acres		124735	124735	124735	124735	124735
	Period of Evaluation (years)		50	50	50	50	50
	Average Annual Habitat Units (AAHU)		38154.2	44024.1	45491.6	51361.5	54296.4
	AAHUs annualized across 50 years		-	39034.7	39254.8	40135.3	40575.6
	AAHU Gain		-	880.5	1100.6	1981.1	2421.3
Cost/Benefit Comparison							
	Total AAHUs		-	880.5	1100.6	1981.1	2421.3
	Estimated Dredging Costs		-	$ -	$ 150,000	$ 340,000	$ 530,000
	Annualized Cost (2.5% discount rate)		-	$ -	$ 5,000	$ 12,000	$ 19,000
	Cost per Average Annual Habitat Unit		-	$ -	$ 5	$ 6	$ 8

Pool 21

			Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables							
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5
2	Distance to Cropland	max 5	5	5	5	5	5
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1
5	Percent Open Water	max 10	1	1	1	5	5
6	Plant Community Diversity	max 10	1	1	1	1	1
7	Important food plant coverage	max 10	0.5	2	3	3	4
8	Percent Area w/ Loafing Structures	max 5	4	4	4	4	4
9	Thermal Protection	max 5	2	2	2	2	2
10	Disturbance in the Fall	max 10	2	2	2	2	2
11	Visual Barriers	max 5	2	2	2	2	2
	TOTAL	max 85	24.5	26	27	31	32
	HSI	total/85	0.29	0.31	0.32	0.36	0.38
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window							
	Acres		57527	57527	57527	57527	57527
	Period of Evaluation (years)		50	50	50	50	50
	Average Annual Habitat Units (AAHU)		16581.3	17596.5	18273.3	20980.4	21657.2
	AAHUs annualized across 50 years		-	16733.6	16835.1	17241.2	17342.7
	AAHU Gain		-	152.3	253.8	659.9	761.4
Cost/Benefit Comparison							
	Total AAHUs		-	152.3	253.8	659.9	761.4
	Estimated Dredging Costs		-	$ 420,000	$ 1,330,000	$ 2,600,000	$ 3,850,000
	Annualized Cost (2.5% discount rate)		-	$ 15,000	$ 47,000	$ 92,000	$ 136,000
	Cost per Average Annual Habitat Unit		-	$ 97	$ 185	$ 139	$ 178

Pool 22

			Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables							
1	Distance to bottomland hardwoods	max 5	5	5	5	5	5
2	Distance to Cropland	max 5	5	5	5	5	5
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1
5	Percent Open Water	max 10	1	1	1	1	1
6	Plant Community Diversity	max 10	1	1	1	1	1
7	Important food plant coverage	max 10	0.5	0.5	2	2	2
8	Percent Area w/ Loafing Structures	max 5	3	3	3	3	3
9	Thermal Protection	max 5	2	2	2	2	2
10	Disturbance in the Fall	max 10	1	1	1	1	1
11	Visual Barriers	max 5	2	2	2	2	2
	TOTAL	max 85	22.5	22.5	24	24	24
	HSI	total/85	0.26	0.26	0.28	0.28	0.28
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window							
	Acres		93861	93861	93861	93861	93861
	Period of Evaluation (years)		50	50	50	50	50
	Average Annual Habitat Units (AAHU)		24845.6	24845.6	26501.9	26501.9	26501.9
	AAHUs annualized across 50 years		-	24845.6	25094.0	25094.0	25094.0
	AAHU Gain		-	0.0	248.5	248.5	248.5
Cost/Benefit Comparison							
	Total AAHUs		-	0.	248.5	248.5	248.5
	Estimated Dredging Costs		-	$ 720,000	$ 1,850,000	$ 3,130,000	$ 4,460,000
	Annualized Cost (2.5% discount rate)		-	$ 25,000	$ 65,000	$ 110,000	$ 157,000
	Cost per Average Annual Habitat Unit		-	#DIV/0!	$ 263	$ 444	$ 633

Starved Rock

			Existing	0.5	1.0	1.5	2.0
Dabbling Duck Model Variables							
1	Distance to bottomland hardwoods	max 5	1	1	1	1	1
2	Distance to Cropland	max 5	4	4	4	4	4
3	Water Depth 4-18 Inches in fall	max 10	1	1	1	1	1
4	Water Depths < 4 Inches in fall	max 10	1	1	1	1	1
5	Percent Open Water	max 10	1	5	5	7	10
6	Plant Community Diversity	max 10	4	4	4	4	4
7	Important food plant coverage	max 10	0.5	3	6	6	8
8	Percent Area w/ Loafing Structures	max 5	4	4	4	4	4
9	Thermal Protection	max 5	3	3	3	3	3
10	Disturbance in the Fall	max 10	3	3	3	3	3
11	Visual Barriers	max 5	2	2	2	2	2
	TOTAL	max 85	24.5	31	34	36	41
	HSI	total/85	0.29	0.36	0.40	0.42	0.48
Dabbling Duck Habitat Unit Calculation - ONE drawdown, 10 year effect window							
	Acres		13601	13601	13601	13601	13601
	Period of Evaluation (years)		50	50	50	50	50
	Average Annual Habitat Units (AAHU)		3920.3	4960.4	5440.4	5760.4	6560.5
	AAHUs annualized across 50 years		-	4076.3	4148.3	4196.3	4316.3
	AAHU Gain		-	156.0	228.0	276.0	396.0
Cost/Benefit Comparison							
	Total AAHUs		-	156.	228.	276.	396.
	Estimated Dredging Costs		-	$ 630,000	$ 1,300,000	$ 1,950,000	$ 4,460,000
	Annualized Cost (2.5% discount rate)		-	$ 22,000	$ 46,000	$ 69,000	$ 157,000
	Cost per Average Annual Habitat Unit		-	$ 142	$ 201	$ 249	$ 397