U.S. Army Corps of Engineers Louisville District

Environmental Flows Workshop Recommendations Report

Green River Basin: Barren River Lake, Rough River Lake, and Nolin River Lake

Sustainable Rivers Program

U.S. Army Corps of Engineers and The Nature Conservancy

January 2026

Cover photo: Nolin River Lake Stilling Basin, Bee Spring, Kentucky (USACE photo)

Contents

List of Figures

Introduction

The Nature Conservancy (TNC) and the U.S. Army Corps of Engineers (USACE) have partnered to form the Sustainable Rivers Program (SRP) to explore opportunities for optimizing reservoir releases and river flows to benefit river ecology while maintaining the federal mandates of reservoir systems across the United States. The mission of SRP is to enhance the health and life of rivers by modifying water infrastructure operations to restore and protect ecosystems, while maintaining or improving other project benefits.

A primary objective of SRP is the implementation of environmental flows (e-flows), defined as the quantity, timing, and quality of water flows necessary to sustain ecosystems. These flows are managed through decisions that manipulate water and land-water interactions to achieve ecological goals. The SRP complements other reservoir-centric water resource projects by demonstrating that a strategic, science-based approach can maintain or enhance benefits provided to the nation.

Background

Green River was site of the first collaboration between USACE and TNC that focused on reservoir management and activities on the Green River have been a catalyst for the entire SRP. Environmental management strategies for Green River were drafted in 1998 and implemented in 2002. Due to the biodiversity and known stakeholder interest in the Green River Basin, USACE reengaged stakeholders to review the current state of the basin 20 years after the initial SRP effort.

In August 2023, the Green River Basin (GRB) SRP Workshop was held at the Mammoth Cave National Park Training Center. The workshop included presentations from various individuals, site visits to areas within the GRB, as well as a series of breakout sessions that were used to facilitate communication about existing conditions and potential opportunities present within the basin. Among the topics and project opportunities discussed was a proposal for a series of e-flow workshops for Barren River, Nolin River, and Rough River Reservoirs.

In 2024, the USACE Louisville District formally proposed adding Nolin River Lake and Rough River Lake to the SRP. Along with Barren and Green River lakes, these facilities were selected because of their position within the greater Green River Basin (GRB) and to complement the inaugural SRP e-flow program implemented at Green River Lake in 1998.

The e-flows workshop identified as an opportunity in 2023 and proposed in 2024 were organized and held in 2025. Modifications to operations of these lakes identified during the e-flows workshop can be used to ameliorate declines in ecosystem health below the dams by improving water quality conditions and downstream habitats, with the goal of protecting the exceptional biodiversity of the GRB. The results of this effort are summarized in this report.

Basin Overview

Encompassing approximately 9,230 square miles in west-central Kentucky and north-central Tennessee, the GRB (Figure 1) is one of the most ecologically diverse river systems in the United States. Barren, Nolin, and Rough rivers are all significant sources of diversity within the greater GRB, with 65 native mussel species and 158 native fishes known from the three tributaries. These include 13 federally listed mussel species. Endemic species in the GRB include six darters, one sucker, one freshwater mussel, and one cave shrimp. Five of these species are distributed throughout the basin. The remaining species are more restricted in their distribution. This extraordinary species richness and high level of endemism make the GRB a high priority for ecological conservation and e-flows.

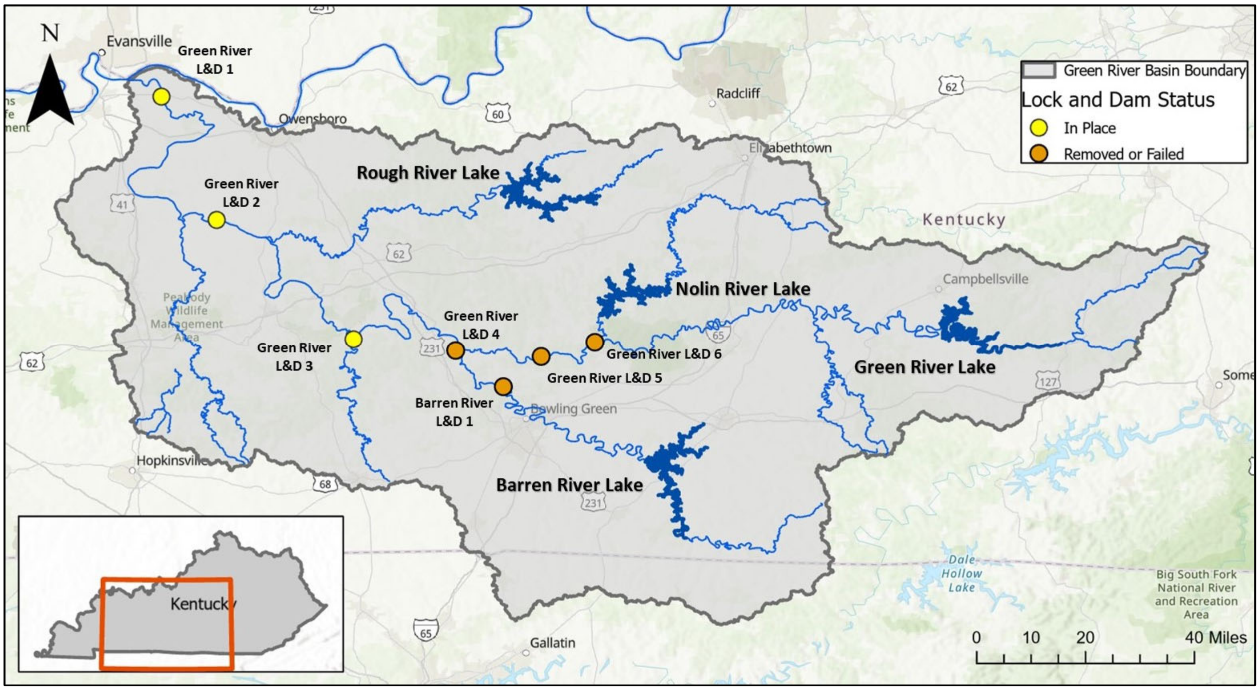

Figure 1. Green River Basin and its water control structures showing the USACE Lake Projects and Locks and Dams throughout the basin.

Lake Operation Capabilities and Parameters

<u>**Nolin River Lake**</u>

Nolin River Lake has a selective withdrawal system with three intakes available that are typically located within the epi-, meta-, and hypolimnions. These intakes allow for the release of flows up to 530 cubic feet per second (cfs). Nolin River Lake has a higher authorized maximum release then the other lakes in the basin, and relatively little seasonal storage. This combination is ideal for delaying fall drawdown (delayed drawdowns were a key strategy for reoperation of Green River Dam and Lake; delayed drawdowns allowed time for in lake water temperatures to mix, which allowed release of warmer waters during drawdowns, which benefited fall spawning mussels).

Barren River Lake

Barren River Lake has a moderate selective withdrawal system with two intakes located near the border of the epi- and metalimnions, respectively, depending on the pool level. These intakes allow for the release of 500 cfs. Barren River Lake has a relatively low authorized maximum release compared to the other lakes in the basin, and the largest volume of seasonal storage. This combination makes delaying the fall drawdown a challenge.

Rough River Lake

Rough River Lake does not have selective withdrawal; both intakes are located within the hypolimnion. Each of these intakes can only release up to 200 cfs. There is also a historical low head dam downstream of the tailwater and this impoundment creates a lentic environment that limits the impact of flow changes that could be made at the reservoir. The release to seasonal storage ratio is favorable for delaying the fall drawdown at Rough River Lake. However, delaying the drawdown may cause an increased risk of higher pools that could clash with a pool restriction that is in place due to embankment concerns. In addition, an ongoing remediation project being conducted at Rough River Lake Dam will limit the operational flexibility of this facility for the next eight years while various physical improvements are constructed.

2025 Environmental Flows Workshop

The GRB e-flows workshop was held on 7 May 2025 in Frankfort, KY. Attendees included USACE personnel, stakeholders from nongovernmental organizations (NGOs), and subject matter experts from state and federal agencies. The goal of the workshop was to discuss and develop flow recommendations and other changes in lake operations designed to reduce negative impacts and/or benefit downstream environments below Barren, Nolin, and Rough River lakes. Among other points of discussion, subject matter experts, lake operations staff, and water managers, developed specific changes in lake operations designed to benefit downstream fish and mussel communities and habitats. Many of the guiding principles and outcomes gleaned from the GRB workshop (outlined herein) may be incorporated into future lake operations, where appropriate.

Stakeholder coordination

Throughout the SRP initiative, coordination with stakeholders was critical to align goals and leverage expertise. The GRB workshop agenda and list of workshop participants are provided in Appendix A.

Workshop kickoff

The goal of the workshop was to facilitate a collaborative discussion to refine problem statements, identify priorities, and develop actionable recommendations for outflows from Barren, Nolin, and Rough River lakes.

Workshop process and goals

Stakeholder meetings: Initial outreach designed to introduce the Licking River (USACE 2025a; USACE 2025c) and Green River SRP efforts to GRB stakeholders was made via a virtual meeting conducted on 30 September 2024. A subsequent meeting with regional experts was conducted to prepare for the pending workshops and served to gather regional insights and outline shared goals.

State of the science: A report entitled *Science and Concepts for Environmental Flows, Green River Basin – Barren River Lake, Nolin River Lake, and Rough River Lake* (USACE 2025b) provides a detailed analysis of historical data for the Barren, Nolin, and Rough rivers, including flow, water quality, and biological data with a focus on ecological impacts and flow alterations that have occurred since these dams were constructed. The report also compiled species-specific life history data to be considered during the workshop. This report was shared with stakeholders on 1 June 2025.

Workshop Results

Summary of key findings and workshop outcomes

The following are major streamflow alterations caused by lake operations and are understood to significantly impact stream ecology:

- Reduced frequency of high flows in the winter/spring.
- Severely reduced magnitude of high flows in the winter/spring.
- Elimination of low flows in the fall particularly in August, September, and October.
- A decrease in summer water temperatures below what is natural particularly in June through mid-July.
- An increase in fall/winter water temperatures above normal particularly between mid-October through January.
- Although dissolved oxygen concentrations regularly meet state standards, there is potentially insufficient dissolved oxygen saturation levels within the Barren River Lake and Rough River Lake tailwaters for what is necessary for fish and mussel recruitment.

General outflow recommendations for all lakes

- **Flow stability and seasonal adjustments:**
    - Maintain stable flows during the fish spawning season (March–July) to support reproductive success.
    - Use short-duration, historically informed flow pulses in early spring to cue fish for spawning.
    - Minimize unnatural high flows in summer to avoid disrupting temperature regulation and aquatic species.
    - Avoid prolonged high-flow events (1,000–5,000 cfs), which negatively impact habitat stability for both fish and mussels.

- **Temperature management:**
    - Match the natural temperature as much as possible, update temperature guide curves to match pre-dam records to inform temperature management efforts.
    - Maintain juvenile mussel growth temperatures at a minimum of 23°C (15 June–15 September).
    - Avoid high summer flows that disrupt temperature regulation and water quality.
    - Adjust trout stocking to eliminate the need for unseasonably low outflow temperatures.
- **Drawdown strategy:**
    - Postpone drawdowns until after lake turnover in late October/November.
    - Use temperature-controlled releases via bypasses for as long as possible in the early fall before transitioning to releases on the main gates.
    - When the transition to higher flows is necessary, affect a gradual temperature change over several days by utilizing multi-levels and gate mixing, if possible.
- **Mimicking natural conditions:**
    - Mimic natural inflows as much as feasible, particularly from April–October, to align with recent observed hydrographs.
    - Base outflow targets on current observed inflows rather than fixed flow rates to reflect natural variability.
    - Maintain dissolved oxygen (DO) at >90% saturation, with continuous monitoring from May–October.
- **Sediment and habitat considerations:**
    - Acknowledge limited ability to influence sediment transport due to dam impacts but monitor downstream habitats.
    - Continue monitoring mussel populations within the basin, including in near dam reaches, where recruitment has declined.
    - Conduct drone-based monitoring of bank erosion within the basin, especially in areas impacted by dam removing on the Green and Barren Rivers.
    - Match flow attenuation rate with natural rates to reduce bank sloughing and erosion.
- **Optimizing large releases:**
    - If large releases are necessary in late spring, conduct them early before lake stratification to prevent hypolimnetic releases.
    - Keep any required pulses for water management short and return to normal flow as quickly as possible.

These recommendations aim to balance ecological health with operational constraints while preserving critical aquatic habitats.

Immediately actionable changes

The workshop resulted in an array of changes that could be started without formal changes to the Water Control Manuals (WCMs) of Barren, Nolin, and Rough River Lake facilities. Additionally, some desired operations changes that are not approved in the current WCMs could be permitted through temporary modifications to lake operations that would need to be reviewed and approved on a year-to-year basis. Feasible operational actions that are prioritized can be implemented will be reviewed and executed to the greatest extent possible beginning in Fiscal Year 2026. The immediate next steps to be taken by USACE include:

- Coordination with Kentucky Department of Fish and Wildlife Resources (KDFWR) on the adjustment of trout stocking dates in the Nolin River Lake tailwater from approximately March through November to a window of November through May. This will eliminate the need for unseasonably cold water to be released in the summer, while also maintaining a recreational trout fishery at these sites.

- Review of spring and summer outflow needs and operations, with the intent of determining the potential to implement e-flow recommendations, including avoiding prolonged high flows as much as possible, implementing spring pulses, maintaining stable flows throughout the spawning season as much as possible, and avoiding high flows after the lake has stratified. These actions would help to regulate temperatures throughout the spawning season as well as foster stable water conditions that would allow for a successful spawn.

- Hypothetical fall drawdown operations have been modeled and reviewed by USACE water managers with the intent of reducing unnaturally high flows in October and November. Each lake has different release capabilities and seasonal storage amounts; Nolin River Lake has the greatest drawdown delay potential, Rough River Lake has the next best potential (apart from the 8-year construction hold), and Barren River Lake has little flexibility. In general, delaying high outflows will allow lake thermoclines to mix, thereby ameliorating the effect of water temperatures in higher releases. This proposed drawdown method would provide more time for juvenile mussels to become established and prepared for winter conditions. Figure 2 provides a graphical comparison of the different capabilities and constraints of each reservoir. Recommendations were applied to detailed simulations to produce the following example of the delayed drawdown alternatives. The different capabilities and constraints of each reservoir can be compared in Figure 2.

- Review of flow attenuation rates based on rates of natural high-water events to determine if water levels are adjusted on an appropriate temporal scale. This action would ensure USACE operations are, to the best of operational abilities of each lake facility, reducing the potential for unnecessary bank erosion and sedimentation.

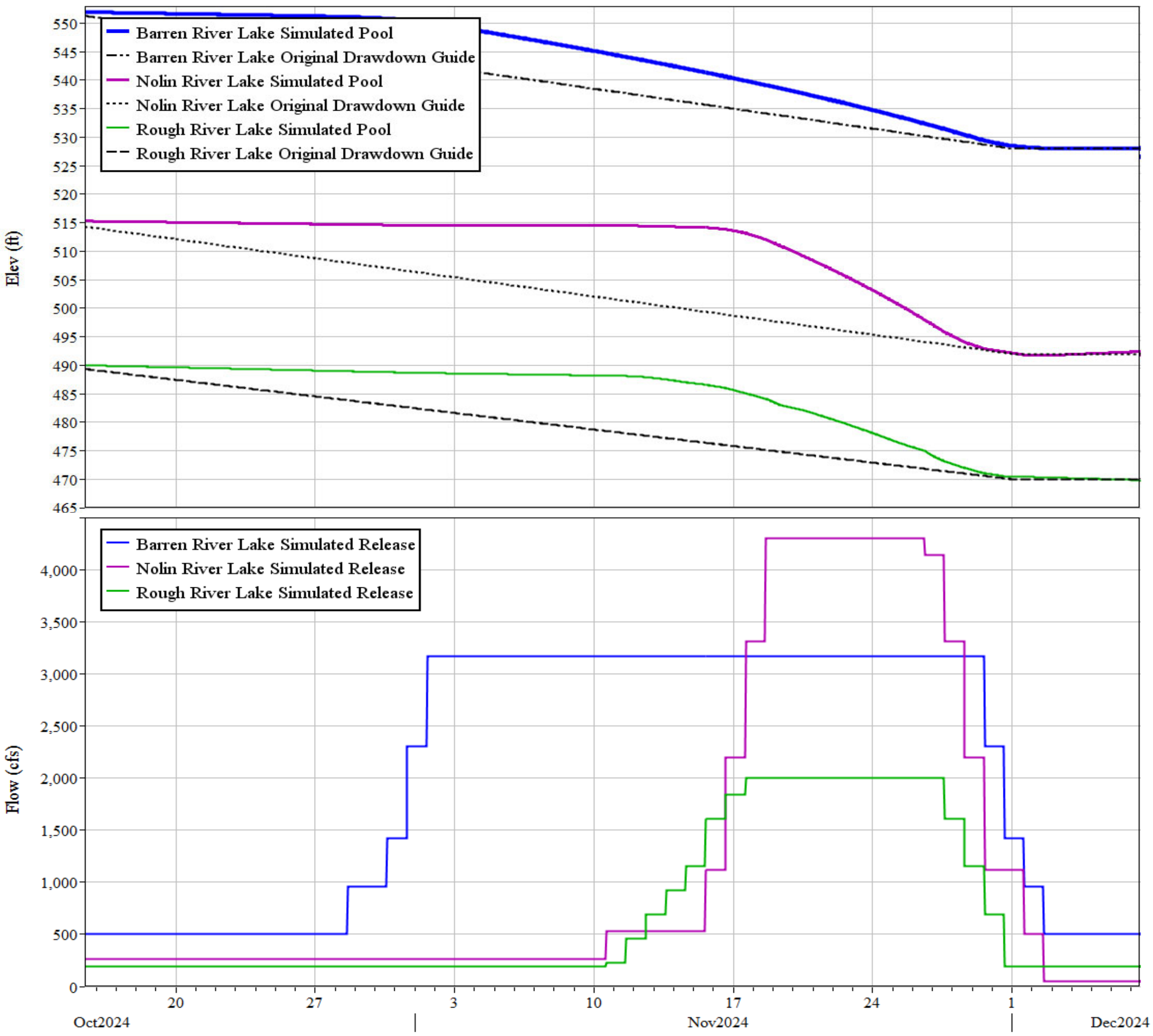

Figure 2. Simulated delayed drawdown alternatives for Barren, Nolin, and Rough River lakes, Kentucky.

Site-specific e-flow guides and recommendations

E-flow guide documents that include site-specific recommendations for Barren, Nolin, and Rough River lakes are included in Appendix B. These documents include recommendations that incorporate e-flow principles into lake operation plans. Operational recommendations incorporate important life history requirements for mussels, fishes, and downstream habitats that were gleaned from the 2025 GRB e-flows workshop, while maintaining the parameters outlined in the existing WCMs for each facility.

In these guides, observed flow events and recommendations from the workshop were simulated using the Corps Water Management System (CWMS) software. A characterization of the inflow amount is highlighted for each event, as many strategies are volume dependent. The guides direct the reader's attention to the downstream result of the release as well as the pool impacts. The reoccurring themes in the scenarios are inflow = outflow, prioritizing bypasses/temperature control, and balancing e-flows with other project authorizations. The guides encourage operators to be creative when applying e-flow recommendations. The guides recognize that we are at the beginning of implementing these changes and new and different strategies can still be developed.

E-flows recommendations formulated in 2025 will be a new consideration for reservoir operations and a transition period will be needed before those recommendations can be fully applied. The guides and lessons learned from implementation will eventually be incorporated into WCMs, eliminating the need for separate documents.

Additional Findings and Topics of Discussion

Water control manual updates

The WCMs for Barren, Nolin, and Rough River Lakes were last updated in 2021, 2020, and 2022, respectively. USACE regulations require that water control plans and manuals be reviewed and updated as needed no less than every 10 years to conform with changes to the project area, technologies, environmental conditions, and several other considerations, including improved understanding of ecological needs (USACE 2016). When future updates to these documents occur, some potential items to consider for revision in the manuals should include the following:

- Delaying the start of the fall drawdown to allow more time for low flows during critical periods.
- Targeting a slightly lower summer pool elevation to allow for more storage of flood waters as well as less extreme drawdown needs.
- Having the ability to maintain pool levels slightly above the targeted pool for a period of time to allow for more temperature-controlled releases when discharging less significant rain events.

- New operational guidance should incorporate best practices learned from the implementation of e-flow strategies.

Structural modification recommendations

As discussed above, there are limitations with the operation of lake facilities that are related to the original constructed design of the infrastructure. It was discussed during the workshop that potential structural modifications be studied to determine if they could effectively increase the operational capabilities for e-flows at lake facilities within the GRB. In particular, structural modifications for increased temperature control at higher flow releases and increased oxygen in outflows were expected to offer the greatest benefit to ecosystems downstream of Barren, Nolin, and Rough River lakes. However, it is important to note that additional studies on temperature and oxygen dynamics occurring below these dams, including determining when and where temperature and oxygen influence occurs downstream and a better understanding of the patterns of dissolved oxygen downstream of projects, are needed. These studies would inform decisions on structural modification recommendations.

In 2015, the *Green River Dam Modifications to Outlet Works* feasibility study (USACE 2015) was completed via a collaboration of USACE and the Kentucky Division of Water. The study focused on various methods for increasing the selective withdrawal discharge capacity of Green River Lake to improve outflow with higher temperatures than current conditions allow. Hypolimnetic releases of cold, oxygen-depleted water have been shown to negatively impact downstream mussel and fish assemblages (Poff and Zimmerman 2010) and similar conditions at Barren, Nolin, and Rough River lakes were implicated in the GRB workshop as factors directly contributing to the decline of mussel assemblages below these facilities (USACE 2025b). The potential exists for the modification alternatives identified in the Green River Outlet Works study to be applied to the Barren, Nolin, Rough River Lake facilities and, because several of the structural alternatives would require only limited modifications to the existing lake infrastructure, may therefore be cost effective solutions to improve water quality of outflows. Modifications investigated in the Green River study include the following:

- **Modification of existing outlet works** – For this alternative, a weir would be attached on the upstream face of the existing low-level inlets. The existing intake structure would be modified by retrofitting one (or all) of the existing low level outlet gates with a new weir structure attached to the upstream face of the intake to allow withdrawals from higher elevations in the reservoir. The weir could surround one intake or all intakes depending on design analysis and water quality modeling results. This alternative allows selective withdrawals from the reservoir at different elevations without a significant impact to the overall discharge capacity of the outlet works.
- **Siphon** – This modification would involve the use of a siphon to discharge the warmer water from the top of the reservoir over the dam into the Green River.

- **Pump station** – This alternative would involve using a pump station to discharge the warmer water from the top of the reservoir over the dam into the Green River downstream. The pump station would consist of a gated intake tower that would allow selective withdrawal from the reservoir. In addition to the pump station, a concrete flume would be constructed to convey the water from the pump station over the dam to the outlet channel to prevent erosion of the dam structure and outlet channel.
- **Submerged weir** – Use of a submerged weir is based on the passing the warmer water over the weir crest into the intake area. In this application, the flexible curtain is suspended a set distance from the water surface using a float system and the bottom is anchored to the lake bottom with ballast and anchors with cables.

The Green River Dam Modification Study ultimately determined that the application of flexible curtain submerged weir would be the most cost-effective application that would have good potential to meet water temperature goals for Green River Lake Dam. In light of the impacts caused by reduced water temperatures within the GRB e-flow project, the structural modifications detailed above have potential to provide increased operational control of outflows that could be used to benefit downstream fish and mussel communities. Further evaluation is warranted to determine the feasibility and ecological benefits of these structural modifications for Barren, Nolin, and Rough River lakes.

Public outreach

USACE plays a vital role in managing water resources in the state of Kentucky and dam operations must consider the needs of the public within the context of all authorized purposes of USACE lake projects, including flood risk management, recreation, water supply, and environment. An important component of USACE’s broader mission is public outreach, whether it be via collaborations with other federal, state, and local agencies, or the general public. Future changes to any approved WCM to incorporate e-flow recommendations, especially those that may impact downstream landowners and agricultural interests, should incorporate public outreach efforts. USACE should continue to actively seek and develop partnerships with communities, local governments, states, tribes, and non-governmental organizations to foster collaboration and improve project outcomes. These outreach efforts are essential in helping the public understand USACE's mission and activities as well as helping USACE practitioners understand community interests. This leads to projects that are more aligned with community needs and helps to build relationships that facilitate collaboration and cooperation on current and future projects.

Target species (2025 GRB environmental flows)

A list of target species was developed through consultations with experts to ensure that life history requirements—such as spawning, recruitment, and habitat needs—were considered when proposing flow prescriptions. All target species for the GRB and accumulated data that was considered during the workshop can be found in the science and concepts report (USACE 2025b).

Cold water and the environmental impacts of trout stocking

As a result of discussions conducted at the GRB workshop, recommendations were made to avoid or modify operating seasonally inappropriate temperatures that are currently made for trout stocking in the summer months (approx. June through September). This time period corresponds with sensitive life history periods of downstream fish and mussel assemblages.

The trout fishery below Nolin River Lake Dam, for example, is managed as a recreational resource maintained by KDFWR, who stocks both rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) in the tailwater. These species are not native to Kentucky, with brown trout non-native to North America. These fish are stocked monthly from approximately March through November when water temperatures are most favorable for this cold-water species survival. The corresponding fishery is distinctly seasonal because few of the trout survive summer as water temperatures exceed their tolerance, though holdover fish have been documented in the Nolin River Lake tailwater. In 2024, 7,000 rainbow trout and 500 brown trout were stocked.

At Nolin River Lake, an effort is made to keep tailwater temperatures at or below 20° Celsius for as long as possible to support the downstream trout fishery. Cold water releases have been shown to negatively impact several life history stages and functions of mussels and fishes, especially during certain times of year (Arnot et al. 2008, Poff & Zimmerman 2010, Galbraith & Vaugh 2011). In an effort to limit the effect of cold water on downstream ecosystems, KDFWR is open to modifying the trout stocking schedule. Creel surveys and experience from the regional fisheries biologists suggest that there is not much angler pressure on trout and it may be possible to adjust trout stocking times to minimize downstream impacts, such as stocking trout during the months when the lake is destratified (approx. November – April).

Ecological monitoring

The need for monitoring was discussed to be of high importance for this effort. Immediately following the GRB E-flows workshop, the Water Quality Team began reaching out to partners to form a working group to develop a monitoring plan.

In support of this effort, fish sampling was implemented within the Licking River in September 2025 with biologists from multiple state and federal agencies and universities participating including the USACE, Kentucky Nature Preserves, KDFWR, and Morehead State University. Data collected during these field surveys will be used as baseline data for the long-term monitoring of fish assemblages and can be used to elucidate the potential effects of future e-flow prescriptions on fish populations downstream.

The USACE Water Quality Team is also planning to further monitor downstream impacts on temperature and dissolved oxygen, which may involve deploying a series of data loggers to study longitudinal and temporal patterns of temperature and dissolved oxygen. Relevant questions to this monitoring include how far significant downstream impacts on temperature and dissolved oxygen persist, the magnitude of those impacts, and how specific operations affect water quality downstream.

There are some site-specific considerations regarding data logger studies. After the workshop, KDFWR provided results from a 2014 study that deployed data loggers below Barren River Lake Dam. This data demonstrated cold temperatures during a high-release event influenced river temperatures for at least 30 river miles downstream (the distance to the most downstream datalogger). The Drakes Creek confluence, the largest tributary to the Barren River below the dam, is approximately 35 miles downstream. Potential locations for future data logger studies in the Barren River include sites upstream and downstream of the Drakes Creek confluence, upstream and downstream of the small rock weir in Bowling Green (the municipal water intake), at the mouth of the Barren and the Green Rivers, above/below the Barren-Green confluence, and at intermediate intervals between these locations. Collecting data at these locations may help clarify thermal differences along the spatial gradient.

KDFWR has also conducted data logger studies below Nolin Lake Dam. However, patterns were less clear and indicated that potentially the temperatures at the dam outlet carried at least to the furthest downstream data logger site, which was 6 miles downstream from the dam. As there are no major tributaries within the 8-mile stretch of the Nolin River between its dam and mouth, it is hypothesized that the dam controls temperatures until the confluence with the larger mainstem of the Green River. Potential locations for data logger studies in the Nolin River are just upstream of the mouth (to avoid potential influence by Green River), and the Green River above and below the Nolin River confluence. It is important to note that this area was formerly part of the pool of Green River Lock and Dam 6 (removed in 2017) and then Lock and Dam 5 (removed in 2024), thus there is potential that thermal dynamics may have shifted from what was previously observed and that the temperature/water quality influence of Nolin River Lake Dam may carry more significantly into the Green River mainstem, which is of significant concern due to the large potential for mussel beds there.

Rough River is, comparatively, a lightly studied system and there is little historic biological data in the river. It is a difficult system to sample as there are few access points available and has been subject to channelization and alteration over the decades. Two low-head dams occur on the Rough River downstream of Rough River Lake: the Falls of Rough old mill dam, located approximately six miles downstream of the reservoir, and the Hartford municipal water supply dam. Both structures impound long reaches of the river, effectively rendering upstream sections unwadeable for considerable distances. Because it is likely that any temperature/water quality influence from the Rough River Lake Dam is ameliorated by the pools formed by these sites, any future data logger studies below Rough River Lake Dam should account for their influence.

Future projects

Barren River Lake was conducting outflows of approximately 4,800 cfs in the spring of 2025 as a result of the record flooding in April, This provides an opportunity to map inundation at that level (this is to be discussed with the Louisville District Geospatial Team) in order to investigate the potential of increasing maximum release amount at Barren River Lake to shorten length of time on main gates. Another key component would be to determine what lands are inundated at different outflow amounts up to the 2025 floods to know when downstream stakeholders would be affected by high flows. Knowing the effects of various outflow amounts would enable USACE to better implement recommended e-flow regimes.

Other opportunities could be investigated using models, building on analyses conducted in the 2017 SRP project for Barren River Lake (USACE 2017).

Conclusions

The environmental flows workshop for GRB represents a pivotal step in advancing the Sustainable Rivers Program's mission to enhance ecological health while balancing operational needs. The GRB has seen a notable decline in biodiversity and species richness, and modified reservoir operations can play a role in restoring natural conditions. The collaborative efforts of stakeholders and experts have yielded a set of science-based recommendations tailored to address the unique challenges of the Barren, Rough, and Nolin Rivers below the major impoundments on each of the rivers. These recommendations underscore the importance of adaptive water management strategies that prioritizes water quality and aquatic biodiversity.

Workshop outcomes provide actionable guidelines to optimize natural flow regimes, flow stability during critical life-history stages for fish and mussels, temperature regulation, and considerations for erosion. Immediate steps, such as revising trout stocking schedules and refining seasonal flow management practices, demonstrate a commitment to implementing practical solutions in the near term. Additionally, the emphasis on stakeholder coordination and ongoing monitoring ensures that adjustments will be informed by scientific data and collaborative input.

By aligning operational goals with ecological priorities, this initiative reaffirms the U.S. Army Corps of Engineers value of integrated water resource management. The strategies outlined in this report aim to restore the ecological integrity of GRB and to serve as a model for sustainable reservoir and river management across the nation. Moving forward, the partnership between the U.S. Army Corps of Engineers, The Nature Conservancy, and other stakeholders will remain critical in advancing the shared vision of a resilient and thriving Green River Basin ecosystem.

Literature Cited

Arnot, C. L., R.A. McKinney, and R.L. Weatherford. 2008. The effects of thermal stratification and dam releases on downstream fish populations: A case study of the Kentucky River. Environmental Biology of Fishes, 83(2),147–158. Available online at https://doi.org/10.1007/s10641-008-9375-5

Galbraith, H.S. and C.C. Vaugh. 2011. Effects of reservoir management on abundance, condition, parasitism and reproductive traits of downstream mussels. River Research and Applications. 27:193–201.

Poff, N. Leroy and J.K. Zimmerman. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology 55:194-205.

USACE. 2015. Green River Dam Modifications to Outlet Works. Continuing Authorities Program Section 1135 Detailed Project Report. 58 pp.

USACE. 2016. Water Control Management. ER 1110-2-240. 70 pp. https://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1110-2-240.pdf

USACE. 2017. Evaluation of Operations Constraints and Opportunities, Barren River Reservoir. Louisville District. Sustainable Rivers Program. 4 pp. https://www.hec.usace.army.mil/sustainablerivers/publications/docs/Barren%20-%20Evaluation%20of%20operations.pdf

USACE. 2025a. Environmental Flows Workshop Recommendations Report: Licking River and Cave Run Lake. Louisville District. Sustainable Rivers Program. 14 pp. https://www.hec.usace.army.mil/sustainablerivers/publications/docs/Licking%20-%20Environmental%20flows%20workshop%20report.pdf

USACE. 2025b. Science and concepts for environmental flows: Green River Basin – Barren, Nolin, and Rough River Lakes. Louisville District. Sustainable Rivers Program. 50 pp. https://www.hec.usace.army.mil/sustainablerivers/publications/docs/Green%20-%20Environmental%20flows%20science%20report.pdf

USACE. 2025c. Science and concepts for environmental flows: Licking River and Cave Run Lake. Louisville District. Sustainable Rivers Program. 49 pp. https://www.hec.usace.army.mil/sustainablerivers/publications/docs/Licking%20-%20Environmental%20flows%20science%20report.pdf

Appendix A

Green River Basin Workshop Attendee List and Agenda

Workshop Attendee List

Name	Agency / Organization	Title / Role / Specialty
Matt Thomas	KDFWR	Ichthyologist & Program Director
Monte McGregor	KDFWR	Aquatic Scientist / Malacologist
Emily Lawson	KDFWR	Biologist
Michaela Lambert	Kentucky Division of Water (KDOW)	Nonpoint Source and Basin Team Supervisor
Mike Compton	Office of KY Nature Preserves	Aquatic zoologist
Becca Winterringer	The Nature Conservancy	Project Advisor, SRP
Zac Wolf	USACE	Limnologist
Kristin Berger	USACE	Biologist
Steele McFadden	USACE	Wildlife Biologist
Jeff Hawkins	USACE	Wildlife Biologist
Jonathan Matthews	USACE	Biologist
Melanie Babin	USACE	Hydraulic Engineer
Alan Ramey	USACE	Barren River Lake Operations Manager
Chris Boggs	USACE	Green River Area Operations Manager
Deryck Rodgers	USACE	Nolin River Lake Operations Manager
Jon Fillingham	USACE	Rough River Lake Operations Manager
Adam Connelly	USACE	Water Resources Section Chief, Louisville District
Taylor Fagin	U.S. Fish and Wildlife Service	Biologist
Wendell Haag	U.S. Forest Service	Research Fisheries Biologist
Colin Duncan	KDOW	
Jeremy Shiflet	KDFWR	Regional Fisheries Biologist
Shelly Morris	The Nature Conservancy	Kentucky Director of Freshwater Conservation
Eric Cummins	KDFWR	Regional Fisheries Biologist

Workshop Agenda

Green River Basins, Sustainable Rivers Program
Environmental Flows Workshop

May 7, 2025

Kentucky Division of Water Headquarters
300 Sower Blvd, Frankfort, KY 40601

Agenda

May 7, 2025
Location: Conference Room A

8:30am	Arrive and Check-in
9:00am	Welcome, Introductions, Overview – *Jonathan Matthews (USACE, Louisville District*)
9:15am	Reservoir Operations in the GRB – *Melanie Babin (USACE, Louisville District)*
9:30am	Break
9:45am	Breakout Groups

Group 1: Mussels (with Jeff Hawkins and Melanie Babin)
Group 2: Fish (with Zac Wolf and Kristin Berger, Steele McFadden)

11:00am	Barren River Lake
12:00pm	Lunch
1:00pm	Barren River Lake
1:30pm	Nolin River Lake
3:00pm	Break
3:15pm	Rough River Lake
4:00pm	Monitoring/Research
4:30pm	Debrief and Closing Thoughts
5:00pm	Adjourn

Appendix B

Environmental flow guides and recommendations for Barren, Nolin, and Rough River lakes.

All examples (and all plots) in this appendix use historical inflow data and observed starting pool conditions from recent years. Reservoir releases and corresponding pool levels are simulated to illustrate e-flows opportunities and approaches related to reservoir operations.

E-flow Guides: Barren River Lake

E-flow release considerations and strategies (Barren River Lake)

The following guidance is most applicable during summer months when stratification of the reservoir causes water quality differences between release levels. The spring filling period is an ideal time to release pulses to trigger spawning and delaying the fall drawdown is the best way to provide warm low releases to encourage juvenile mussel growth. All normal WCM guidance is still applicable (min/max release rules). Flood mitigation, recreation, and other authorized purposes should be balanced as well.

Low flows (temperature regulation)

The highest priority months for low flows are May-November. During these months it is best for the reservoir releases to match inflows to benefit the aquatic environment downstream. Minimum flow requirements from the WCM must still be followed but consider releasing more than the minimum if conditions allow. Always use the current inflow as a guide for the outflow when possible. Apart from low flows being natural in the summer, the temperature regulation associated with the bypass multi-levels should be a high priority. Native organisms are adapted to warm water temperatures during this time of year and need these conditions to survive.

Pool impacts

The Port Oliver boardwalk experiences overtopping in some areas at elevation 553.5 – 554 feet (ft). This is a popular recreation site; consider impacts on recreation if this pool level (1.5 – 2 ft over summer pool) will be held over weekends or for more than a week. The State Park beach is closed at elevation 556 ft. The pool should not be held near this level for e-flow purposes unless it is very early/late in the recreation season and the State Park has indicated that the beach is already closed (or they are willing to close it for other reasons). There are many houses and private docks on the lake and water levels are tracked closely by the public.

High flows

Releases that require the use of the main gates may have a significant impact on the temperature and chemistry of the riverine habitat downstream. When downstream water levels allow, release water as quickly as possible. The goal should be to return to bypasses as soon as practical. Consider using the previous 24-hr inflow values calculated as the target flow for the release. If a high release (>2,000 cfs) needs to be held longer than two days, then additional consideration should be given to reducing the flow slowly after the peak release. The slow reduction approximates natural events more closely and will help prevent bank sloughing in the downstream channel.

Tailwater impacts

The impacts of large releases on tailwater recreation are minimal at Barren River Lake. The sidewalks, parking lot, and other access points are still accessible during large releases. Flows above 1,000 cfs may start to impact less experienced boaters. Advanced notice of high flows (on social media) would benefit downstream recreational users but it is common for Barren River Lake to adjust the flow rapidly over the course of a single day without prior notice.

Example e-flows (Barren River Lake)

The following examples use historical inflow data from recent years. Starting pool elevations are observed and inflows have been calculated from the observed elevation change of the lake. These scenarios do not include the downstream conditions (like elevated control points or inspections). The purpose of these examples is to better explain the flow recommendations from the SRP stakeholders and help Operators and Water Managers identify events that are ideal for e-flow strategies. While these examples do not directly call out other considerations, all reservoir authorizations must still be followed when releasing an e-flow.

Barren River Lake, February/March 2024 – Varied winter releases

In late winter (early spring) 2024, Barren River Lake experienced high inflows for more than a week. This time of year, is likely that flooding may restrict reservoir releases. For this example, the assumption is that high releases are non-damaging to downstream communities. While it is advantageous to store flood water that could have been damaging, storing water in the lake unnecessarily only results in less storage being available later in the season.

In this case, Barren River Lake must maintain a high outflow for the entire week to avoid storing water. However, matching inflows means that releases should vary with the inflow. The initial simulated release of 2,600 cfs approximates the current inflow value and causes the pool to drop back to the guide curve by March 2nd. Once the pool reaches elevation 528 ft, the simulated release is lowered to 1,000 cfs to better match inflows. The pool then rises, because inflow is higher than outflow, and the following day the simulated release is increased to 2,000 cfs. Alternatively, releases could be changed every day which may result in a steadier pool level. If time allows, consider making daily adjustments to follow natural inflows more closely.

This is an example of varying the releases to match inflows. Instead of releasing the same amount for the entire week, multiple release changes try to match the inflow and hold the lake at the winter pool level. Figure 3 shows simulated examples of varied winter releases at Barren River Lake, Kentucky.

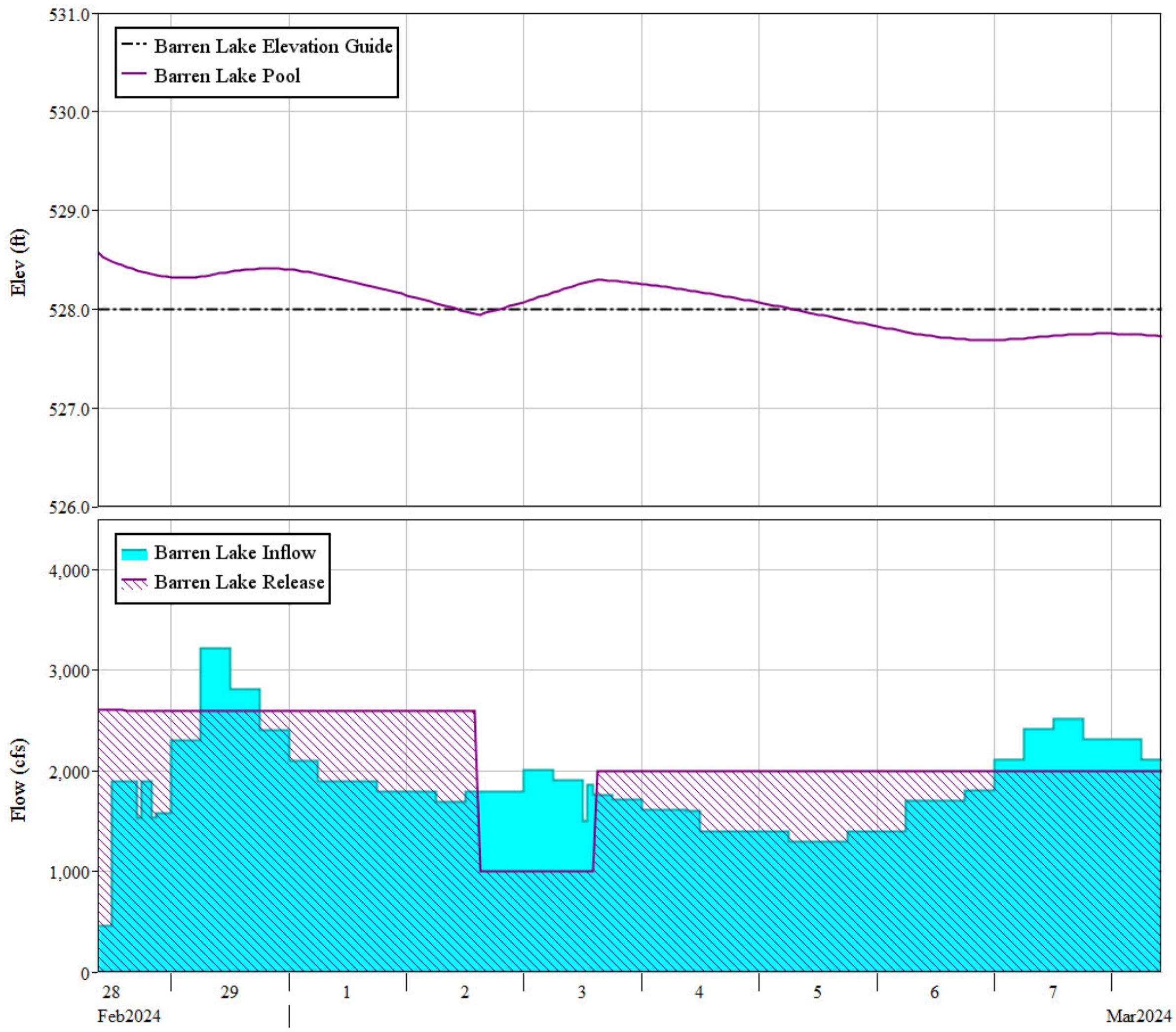

Figure 3. Barren River Lake, February/March 2024 – Varied winter releases (e-flows example).

Nolin River Lake, March 2023 – Spawning pulse during fill

In late March of 2023, there was a small rain event at Nolin River Lake. Instead of storing all of the inflow and filling early, this simulation shows how a pulse release can provide a spawning signal for downstream fish while still following the fill target.

To reduce the amount of gate changes in a single day, 3,000 cfs is initially released in the simulation, followed by 5,200 cfs. The volume of this simulated release is less than the total inflow so, after the pulse, the reservoir is still 5 ft higher than before the start of the event. Figure 4 highlights the recommendation to evacuate storage as quickly as possible and provide high flow pulses in the spring to trigger fish spawning.

This example at Nolin is included in the Barren River Lake section because it illustrates how e-flow spawning pulses could be provided in spring, which is relevant for both reservoirs.

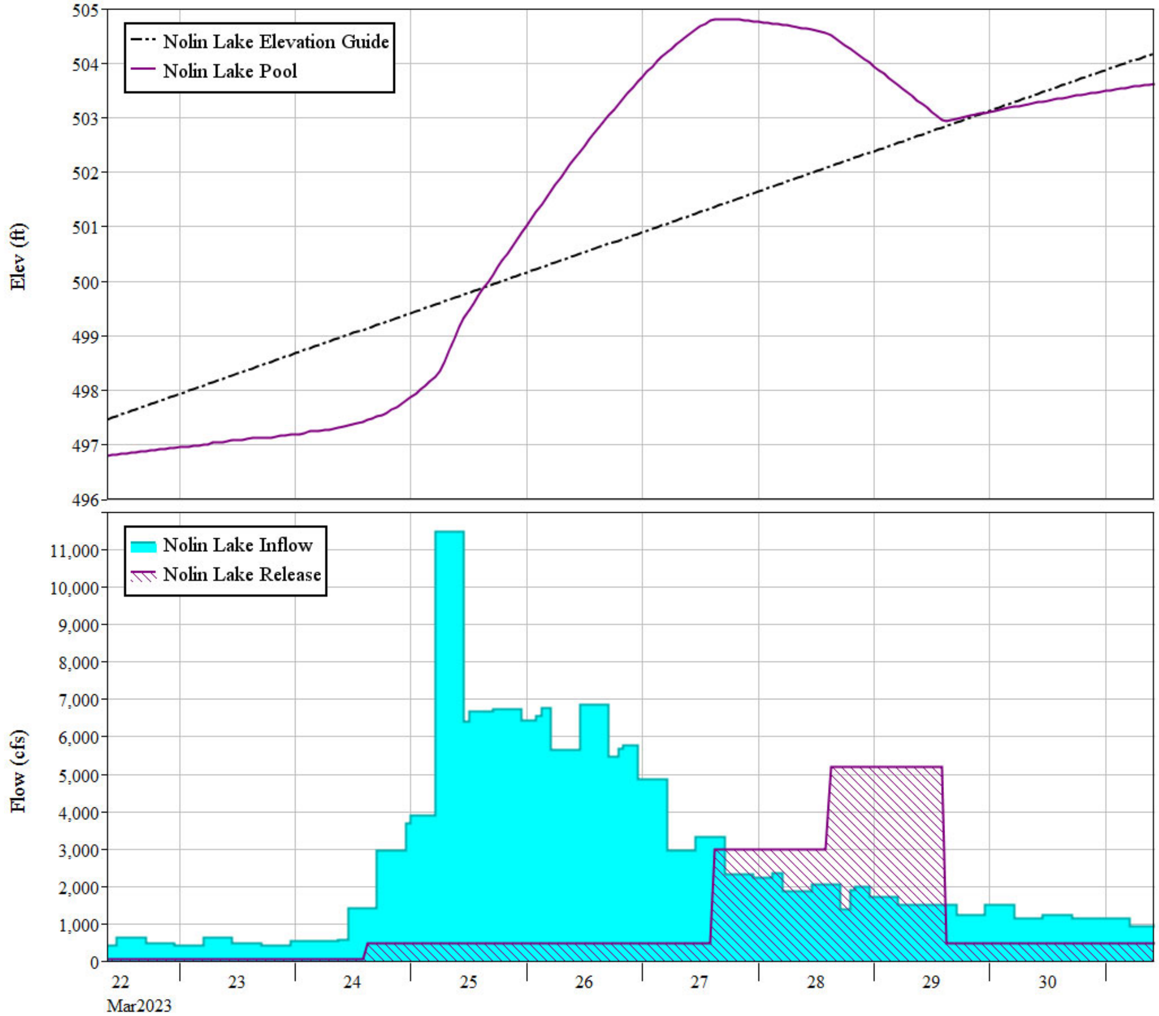

Figure 4. Nolin River Lake, March 2023 – Spawning pulse during fill (e-flows example).

Barren River Lake, July 2023 – Pulse Release

In July 2023, Barren River Lake experienced a small inflow event. Sometimes flooding on the Barren and Green Rivers can extend into the summer months, this example assumes that the rivers downstream are below flood levels.

At the start of the simulation Barren River Lake is at a low release (500 cfs) providing warm water to the river downstream. A small inflow event starting on July 20^{th} causes the pool to rise. There are recreation impacts at the Port Oliver boardwalk starting at elevation 553.5 ft. By starting a simulated high release on July 21^{st}, the reservoir passes inflow efficiently preventing pool rise. A medium high release of 2,500 cfs is held for two days, and the pool returns to summer pool levels. Warm water releases can begin again, using bypasses to release 500 cfs. Figure 5 illustrates the recommendation to maintain seasonally appropriate warm low flows in summer, while evacuating storage as quickly as possible.

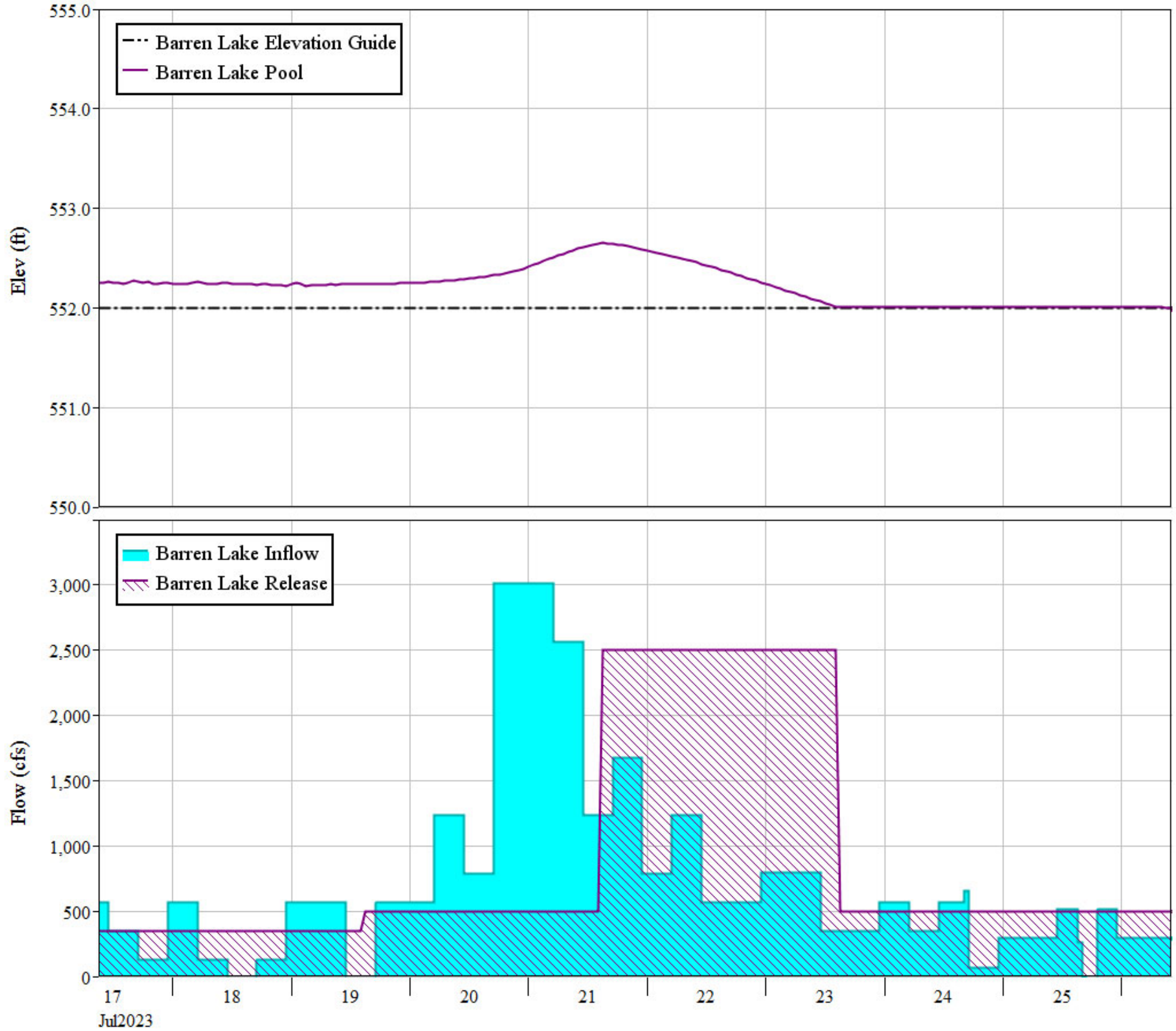

Figure 5. Barren River Lake, July 2023 – Pulse release (e-flows example).

Barren River Lake, July 2024 – Delayed pulse release

In July 2024 Barren River Lake experienced two small inflow events. Sometimes flooding on Barren and Green Rivers can extend into summer months. This example assumes that the rivers downstream are below flood levels.

At the start of the simulation, the pool is less than 0.5 ft above summer pool (552 ft). Barren River Lake is at a simulated low release (500 cfs) providing warm water to the river downstream. The pool rises an additional ~0.5 ft after a small inflow event on July 18th. Maybe there is some concern that the Port Oliver boardwalk will overtop over the weekend (elevation 553.5 – 554 ft). A medium pulse of 2,500 cfs is started on Friday July 19th and held for two days in the simulation. The pool falls slightly below the guide curve and releases are reduced to 500 cfs, simulating a warm low flow (approximately the max bypass capacity). A second small inflow event happens on Monday

July 22nd but the final reservoir level is less than 0.5 ft above summer pool. Low releases can be held during the week since the pool level is only slightly elevated. Figure 6 shows a simulated example of a delayed pulse release at Barren River Lake.

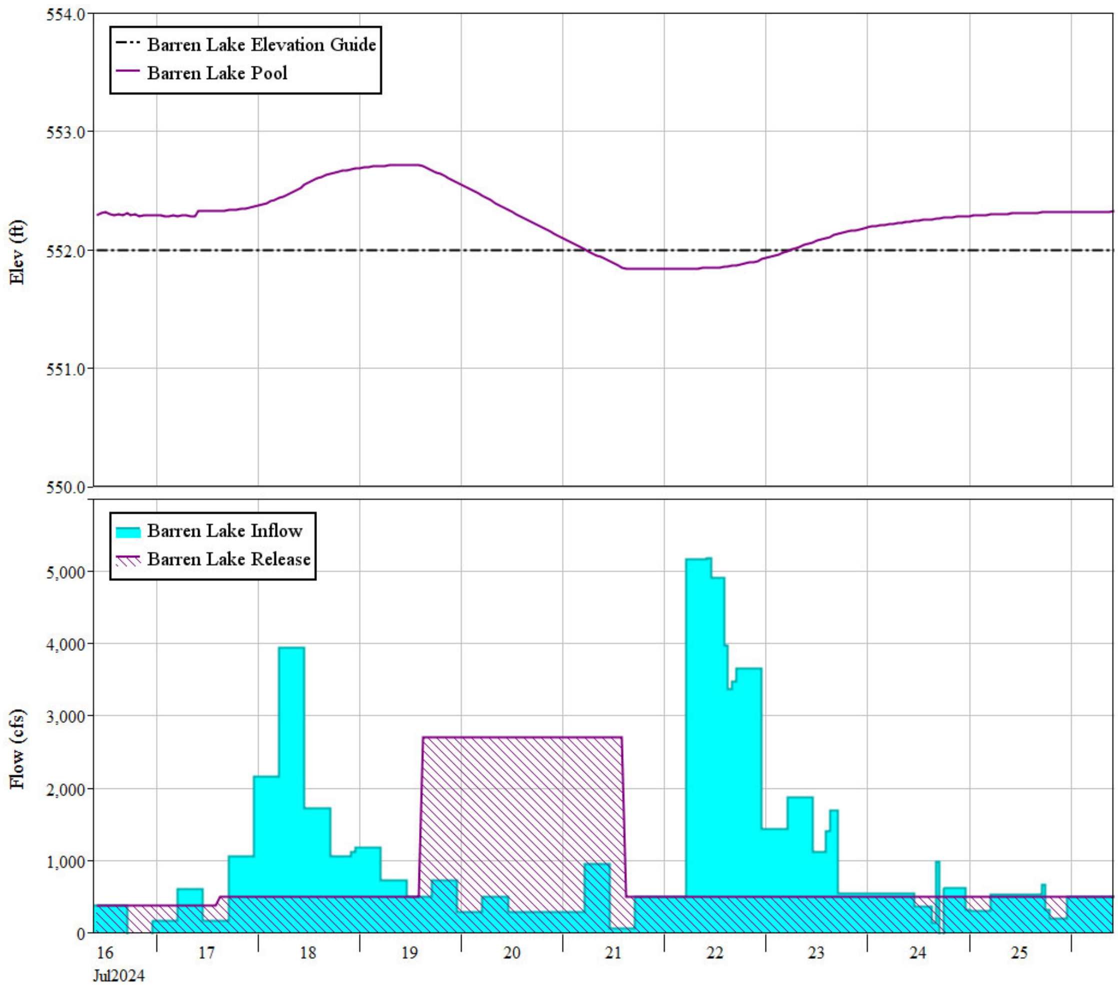

Figure 6. Barren River Lake, July 2024 – Delayed pulse release (e-flows example).

This example highlights the recommendation to maintain seasonally appropriate warm low flows in the summer, by holding the pool level slightly high. When the pool does need to be drawn down, storage is evacuated as quickly as possible.

Delay drawdown

Late summer (August to October) is a critical time for juvenile mussels and other aquatic organisms. Low flows and warm water are important for juvenile mussels that need to settle into streambeds to begin growing after detaching from fish hosts. The critical time for the Barren River Basin aquatic ecosystem is from May to November. Long duration cold releases during these months disturb natural conditions. Please provide flow via bypasses for as long as possible before using main gates to complete the drawdown.

A dry year delayed drawdown scenario is shown in Figure 7. The graphic was created with the most current CWMS modeling suite, using the 2024 water year starting conditions and idealized 50 percentile inflows ranging from 195 – 440 cfs. Release amounts and volumes evacuated are based on Barren River Lake's specific capabilities and constraints. While idealized, this drawdown is possible to achieve.

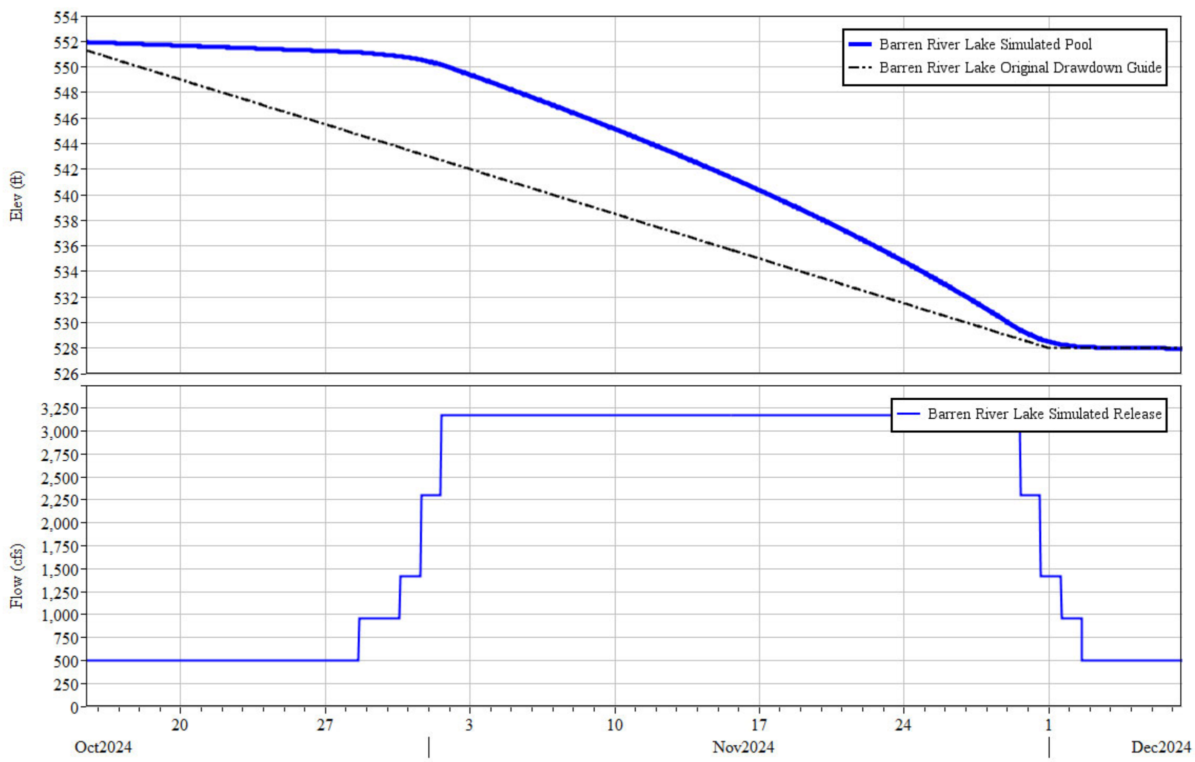

Figure 7. Barren River Lake, 2024 – Delayed drawdown (e-flows example).

This delayed drawdown scenario requires the maximum release of flows no higher than 3,200 cfs until December 1st, as stated in the WCM. If the lake is at summer pool levels in mid-October, it may be possible to delay the drawdown until the end of October or early November as shown in Figure 7. Delayed drawdowns will be hard to implement in wet years when flood storage recovery is a priority. Changes in flow regime from year to year is natural, so responding to the current hydrology is appropriate. Delaying the drawdown is the most direct way to simulate natural river conditions on the Barren River within the project authorizations and limitations.

Pre-release using bypasses

The drawdown example above (Figure 7) shows how ~500 cfs can be released during the start of the drawdown period. This lower release is the max capacity of one bypass and allows for multi-level selection (temperature control) while still drawing the pool down slightly. Biologists that work on Barren River regularly have confirmed that 250 - 500 cfs is a "low" flow and will simulate natural conditions adequately. This magnitude of release may not be appropriate on smaller rivers.

Temperature ramp

At the beginning of the drawdown, there should be a multi-day or weeklong transition to cooler temperatures. Main gate releases will drop tailwater temperature significantly and these effects could persist to the confluence of Barren and Green rivers (depending on natural water conditions). Especially in times of drought or low water, temperature and flow changes should be done as slowly as practical. There is usually a natural temperature drop in the fall that is triggered by air temperatures and shorter days. Continue warmer releases until this natural drop has started, if possible. Based on the natural temperature regime in nearby watersheds, the transition should be limited to a decline of 2°C maximum per day. Large drops in temperature (10°C) should be planned over a week. Consider mixing bypass levels to slow the transition further and mixing bypasses with the main gates for the final transition. Downstream temperatures are influenced by natural runoff and reservoir releases. Natural uncontrolled runoff will be very small at this time in comparison with the maximum release from the reservoir. As releases are increased the reservoir releases will start to dominate the volume of the entire river and downstream water temperatures will drop further. Once main gates have been activated and multi-levels can no longer be used, outflows should still be slowly increased due to this temperature/volume dynamic.

Maximum release

Releasing the maximum outflow would allow the drawdown to be completed in the shortest period. Therefore, it is recommended to target max flow in the delayed drawdown plan. However, humans and aquatic organisms will not be expecting high cold flows in the fall. Transition to maximum release should be done over several days or even a week if time allows.

Flow reduction for bank stability

Barren River Lake Dam has specific rules for how quickly gates/flow can be increased and decreased. For e-flows it is recommended to change the gates/flow even slower when reducing outflow. Drawing out the receding limb of the release hydrograph has two main benefits: it is the best simulation of a natural flood and it will reduce potential bank sloughing. Recent hydrographs of natural events (inflows) can be used as a template for the reduction but, to release the full volume necessary, it may be advantageous to reduce flow at an even slower rate. The example shown above (Figure 7) accounts for volumetric differences between target summer and winter pools. In wetter years more volume may need to be released.

Releasing non-crop season maximum (deviation required)

For larger lakes like Barren River Lake or for particularly wet years, a delayed drawdown would be more successful if the reservoir is allowed to release the non-crop season release. This may not be possible prior to December 1st due to downstream conditions as the tailwater area has farmland that can be negative affected by high water levels. Figure 8 shows how increasing the release can shorten the duration of the drawdown period, allowing for low flows until early November. The release of 4,000 cfs in early December reflects the maximum release allowed after December 1st.

Delaying the drawdown into December would require a modification to the existing water control manual that would require prior approval by the USACE Lakes and Rivers Division.

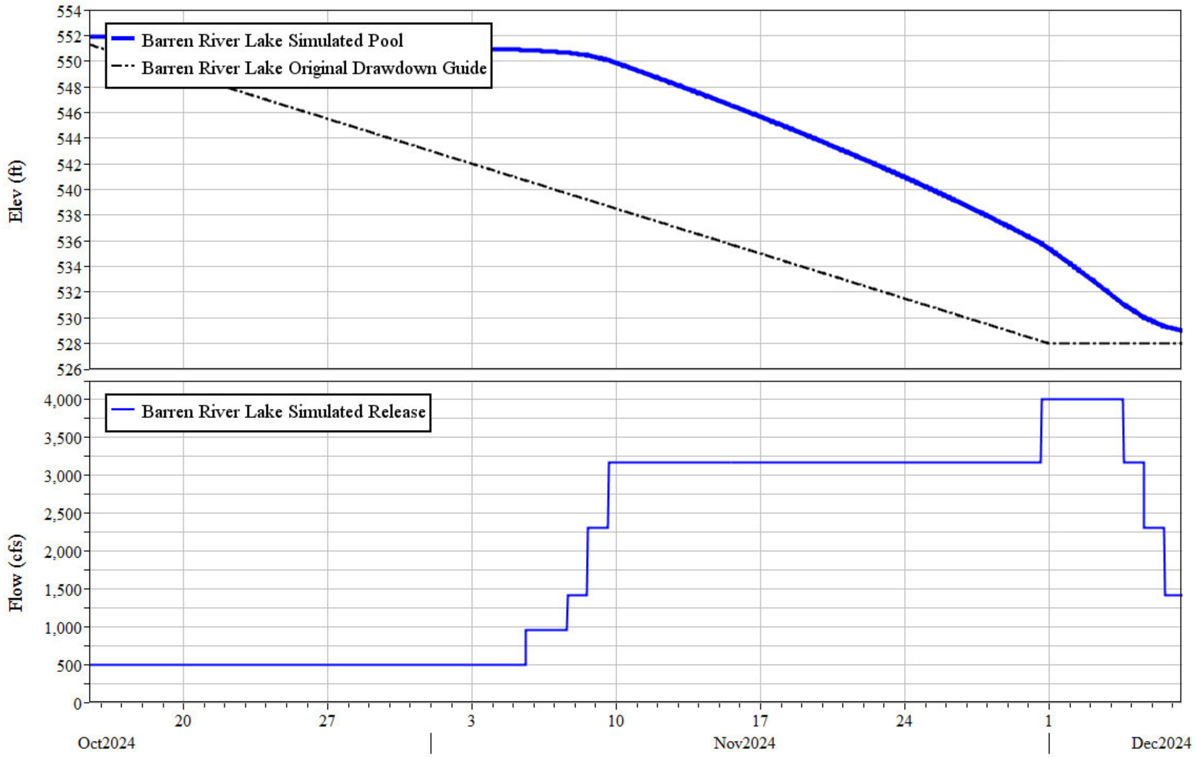

Figure 8. Barren River Lake, 2024 – Delayed drawdown (e-flows example 1).

The final modeled alternative would require a planned deviation request and significant downstream coordination. There is an exception for the allowable maximum release at Barren River Lake to be temporarily increased to 6,000 cfs (Figure 9). This release amount could allow the drawdown to be delayed until mid-November. However, there are many impacts to downstream farmers at release amounts over 4,000 cfs.

This alternative would be the most difficult to implement as it would require the most coordination with downstream stakeholders. It is likely that inundation maps would need to be developed by USACE Water Management before consulting downstream stakeholders. Biologists concerned with the health of Barren River have requested that the drawdown be delayed as long as possible, so this alternative is favored ecologically because it allows the longest delay.

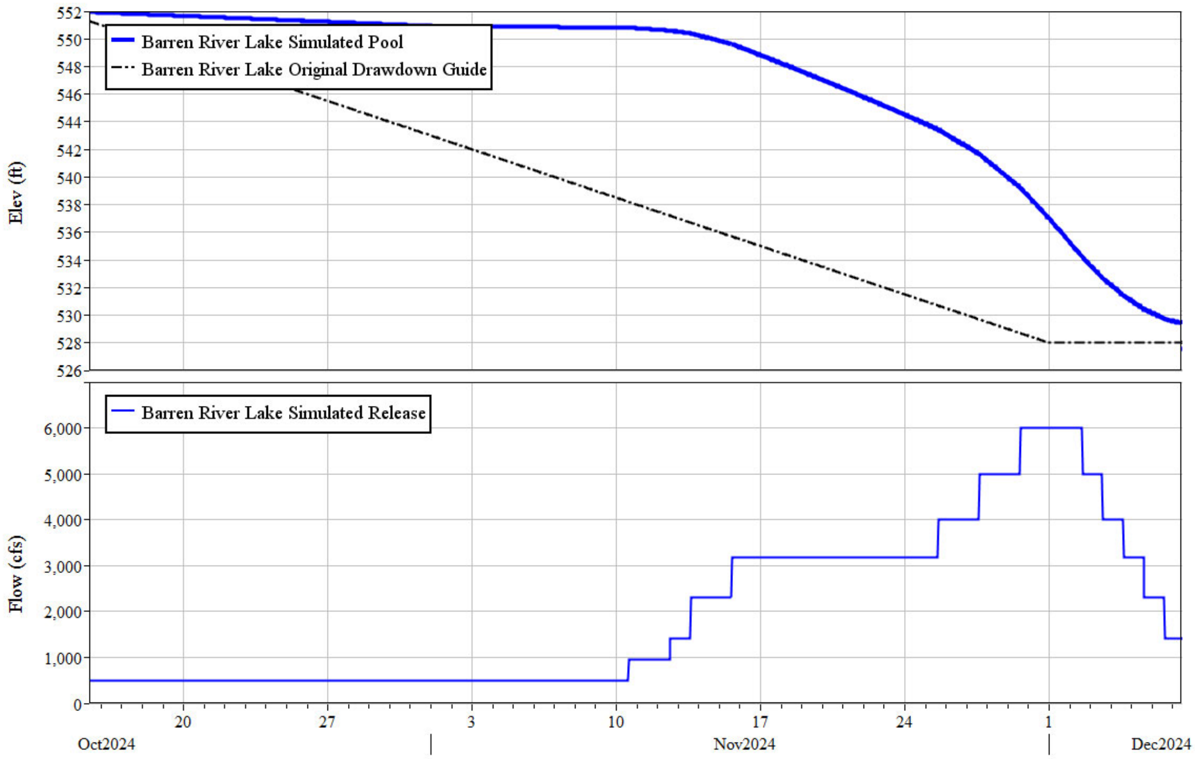

Figure 9. Barren River Lake, 2024 – Delayed drawdown (e-flows example 2).

Variations due to current conditions (Barren River Lake)

Figure 10 shows the actual drawdown from 2024, the year preceding the e-flows recommendations. This graph has been included as an acknowledgement that every water year will be different; therefore, each drawdown will be different. In 2024, for instance, the drawdown was supposed to begin on October 1st and was delayed briefly to accommodate a downstream concern. To compensate, outflows were increased in late October. There were also several rain events in November, which led to prolonged high releases. A good drawdown plan will have contingencies and provide flexibility for current conditions as they arise.

The drawdown at Barren River Lake is one of the most challenging in the district due to the amount of storage in the seasonal pool and the lower release requirements. There will be years when a delayed drawdown is not practical. The goal should be to target a longer delay in dry years, and in wet years focus on incorporating the other e-flow strategies (temperature ramp, max release, flow reduction for bank stability) into the traditional schedule.

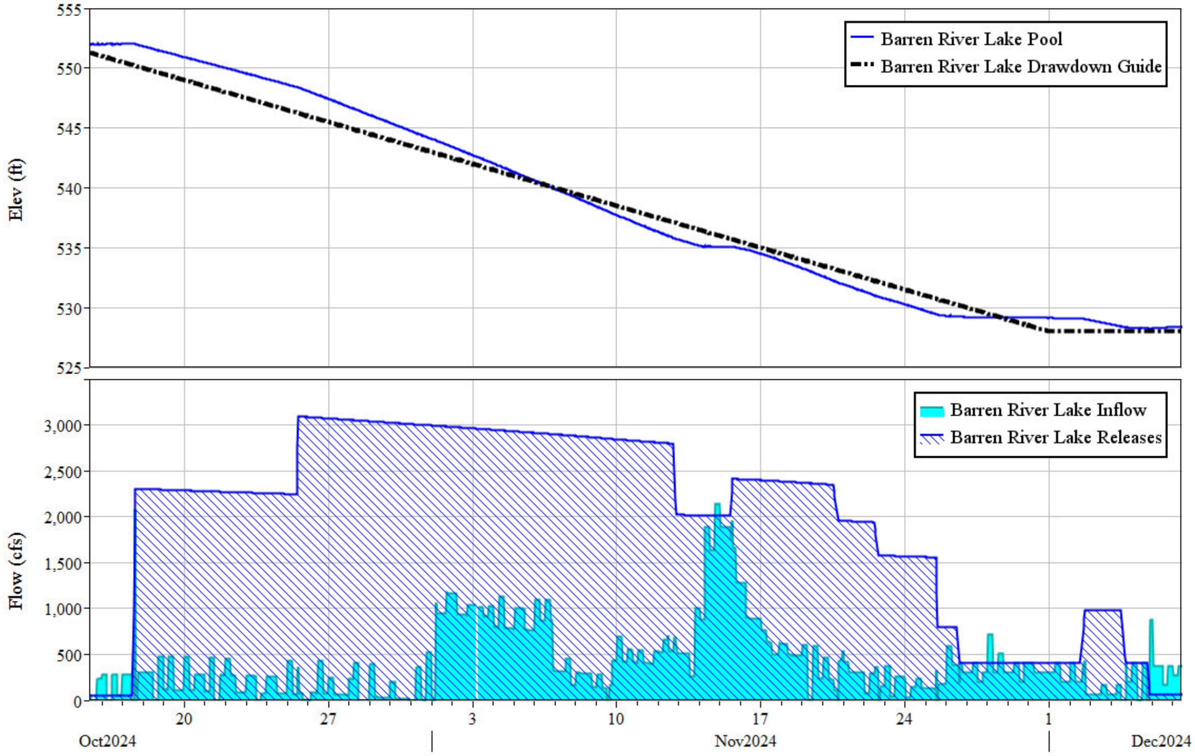

Figure 10. Barren River Lake drawdown, 2024.

E-flow Guides: Nolin River Lake

E-flow release considerations and strategies (Nolin River Lake)

The following guidance is most applicable during summer months when stratification of the reservoir causes water quality differences between release levels. The spring filling period is an ideal time to release pulses to trigger spawning and delaying the fall drawdown is the best way to provide warm low releases to encourage juvenile mussel growth. All normal WCM guidance is still applicable (min/max release rules). Flood mitigation, recreation, and other authorized purposes should be balanced as well.

Low flows (temperature regulation)

The highest priority months for low flows are May-November. During these months, it is best for the reservoir releases to match inflows to benefit the aquatic environment downstream. Minimum flow requirements from the WCM must still be followed but consider releasing more than the minimum if conditions allow. Always use the current inflow as a guide for the outflow when possible. Apart from low flows being natural in the summer, the temperature regulation associated with the bypass multi-levels should be a high priority. Native organisms are adapted to warm water temperatures during this time of year and need these conditions to survive.

Pool impacts

The Iberia Swim Beach is 6 ft deep at elevation 515.5 ft. The pool should not be held for more than a few weeks above this level for e-flow purposes unless it is very early/late in the recreation season and the beach is already closed. The Wax Marina walkway experiences overtopping in some areas at elevation 517 ft. This is a popular recreation site, so consider impacts on recreation if this pool level (2 ft over summer pool) will be held over weekends or for more than a week. In general, try to avoid impacts over weekends. There are many houses and private docks on the lake and water levels are tracked closely by the public.

High flows

Releases that require the use of the main gates may have a significant impact on the temperature and chemistry of the riverine habitat downstream. When downstream water levels allow, release water as quickly as possible. The goal should be to return to bypasses as soon as practical. Consider using the previous 24-hr inflow values calculated as the target flow for the release. If a high release (>2,000 cfs) needs to be held longer than two days, then additional consideration should be given to reducing the flow slowly after the peak release. The slow reduction approximates natural events more closely and will help prevent bank sloughing in the downstream channel.

Tailwater impacts

The impacts of large releases on tailwater recreation are minimal at Nolin River Lake. The sidewalks, parking lot, and other access points are still accessible during large releases. Flows above 500 cfs may start to impact less experienced boaters, so try to avoid flows higher than that over the weekend. Advanced notice of high flows (on social media) would benefit downstream recreational users. It is common for the Nolin River Lake Office to receive formal requests for releases changes, so posts should help explain the cause of the release (e-flows) so that the public does not perceive that another entity is being prioritized. In general, the public is tracking releases at Nolin River Lake closely because it is a popular recreation site.

Example e-flows (Nolin River Lake)

The following examples use historical inflow data from recent years. Starting pool elevations are observed and inflows have been calculated from the observed elevation change of the lake. These scenarios do not include the downstream conditions (like elevated control points or inspections). The purpose of these examples is to better explain the flow recommendations from the SRP stakeholders and help Operators and Water Managers identify events that are ideal for e-flow strategies. While these simulated examples do not directly call out other considerations, all reservoir authorizations must still be followed when releasing an e-flow.

Nolin River Lake, March 2023 – Spawning pulse during fill

In late March 2023, there was a small rain event at Nolin River Lake. Instead of storing all the inflow and filling early, this simulation shows how a pulse release can provide a spawning signal for downstream fish while still following the fill target.

To reduce the amount of gate changes in a single day, 3,000 cfs is initially released, followed by 5,200 cfs. The volume of this release is less than the total inflow so, after the pulse, the reservoir is still 5 ft higher than before the start of the event. Figure 11 highlights the recommendation to evacuate storage as quickly as possible and provide high flow pulses in the spring to trigger fish spawning.

Nolin River Lake, July 2023 – Delayed large pulse

The following events took place in early July 2023 at Nolin River Lake. Flooding on the Nolin and Green Rivers can sometimes extend into summer months. This example assumes that the rivers downstream are below flood levels.

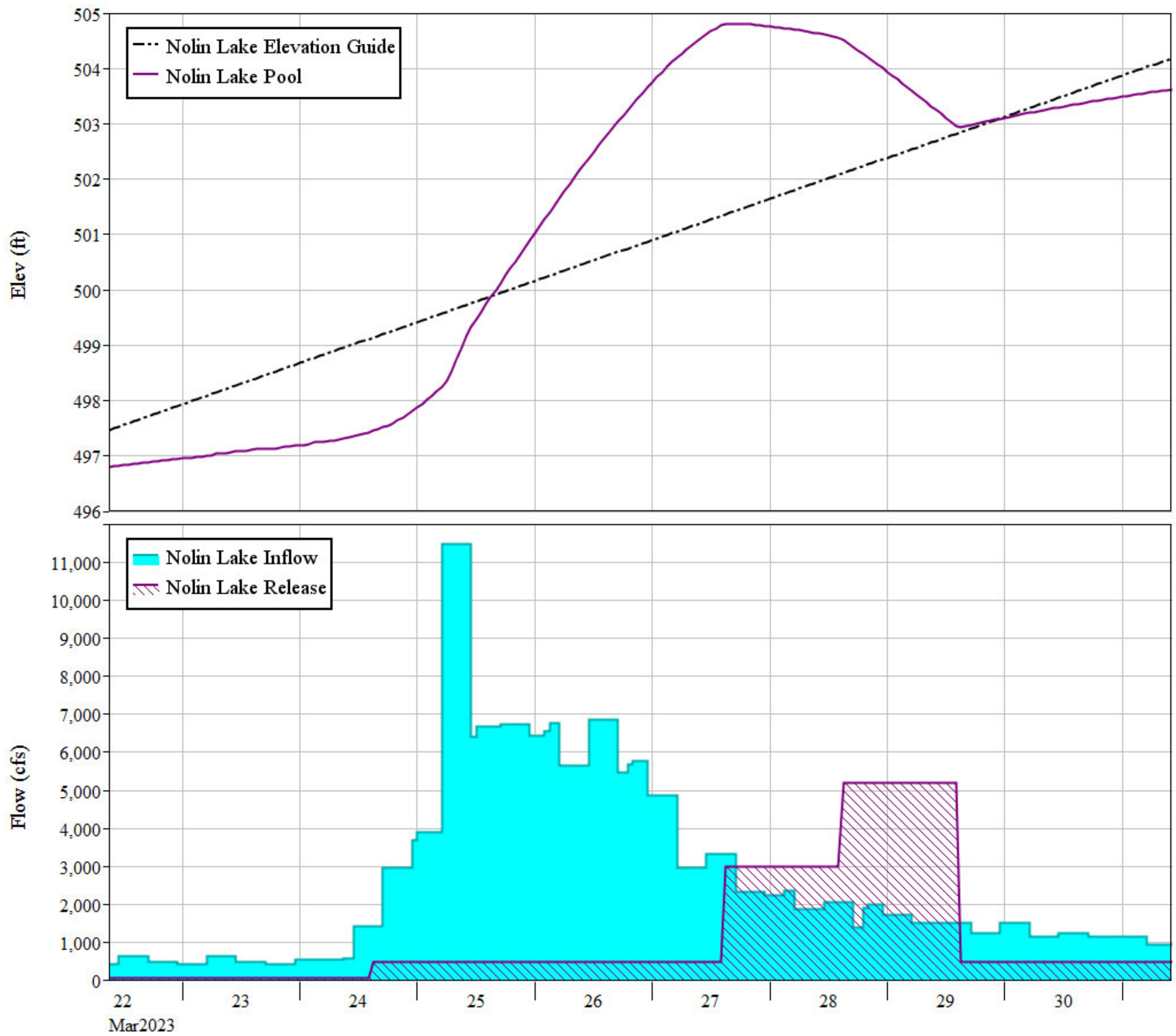

Figure 11. Nolin River Lake, March 2023 – Spawning pulse during fill (e-flows example).

A rain event on July 2nd caused the reservoir to reach an elevation of 518 ft (3 ft above summer pool). This pool rise has recreational impacts for Iberia Swim Beach and the Wax Marina, restricting access and requiring walkway adjustments. Releases for this simulated event do not start until July 4th and the peak outflow (5,400 cfs) is slightly lower than the peak inflow (~7,500 cfs). The simulated pulse event starts with a transitional flow of 2,700 cfs to reduce the amount of gate changes needed in a single day. Before and after the pulse a low outflow (500 cfs) is released to allow temperature management (Figure 12). For e-flows, if downstream conditions allow, starting releases on July 2nd or 3rd would have resulted in a lower pool level and less recreation impacts.

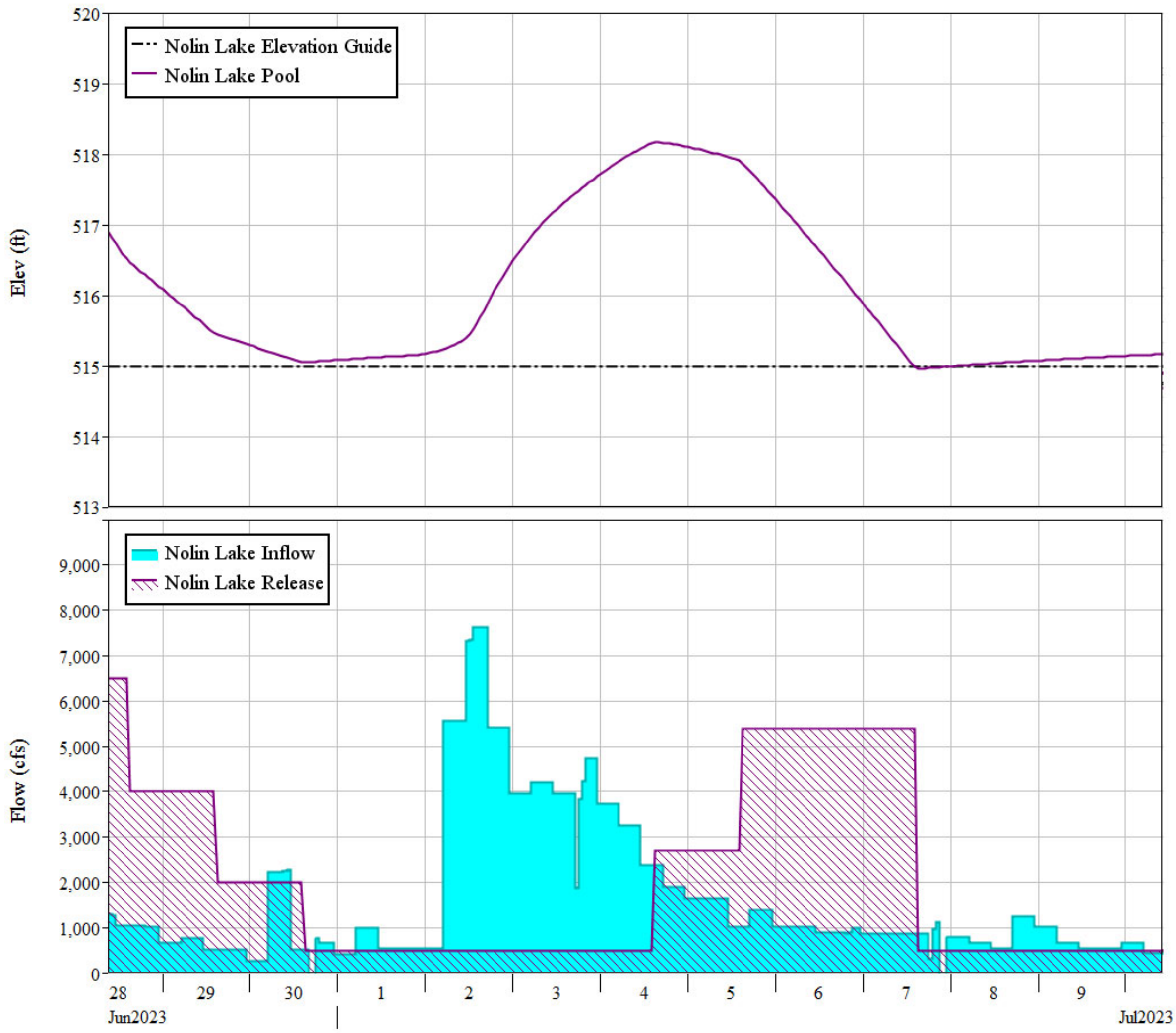

Figure 12. Nolin River Lake, July 2023 – Delayed large pulse (e-flows example).

Nolin River Lake, September 2022 – 24-hour pulses

In early September 2022, there was a small rain event at Nolin River Lake. Instead of storing the entire inflow volume and letting the pool rise; this simulation shows how a pulse release during, or shortly after, the event can limit the pool rise. Typically, the Nolin and Green rivers are very dry in September, so during this season a pulse release could be ecologically beneficial.

The simulated 24-hour pulse (1,000 cfs) starts on September 6^{th}, continues over night, and concludes the next day. Before and after the pulse event, low outflows that allow for temperature management are simulated. The low outflow (150 cfs) after the pulse event is lower than the inflows (~ 250 cfs) so the pool rises and another pulse (1,500 cfs) is needed starting on September 11^{th} to release the additional stored water. Again, the release following the pulse is low enough to allow temperature management. In this example, the pool does not rise enough to impact recreation. An alternative way to implement e-flows would be to remain at a low outflow if it could be forecasted that the pool would not rise past elevations 515.5 (Iberia Beach) or 517 (Wax). Figure 13 highlights the recommendation to maintain seasonally appropriate warm low flows in the early fall while evacuating storage as quickly as possible.

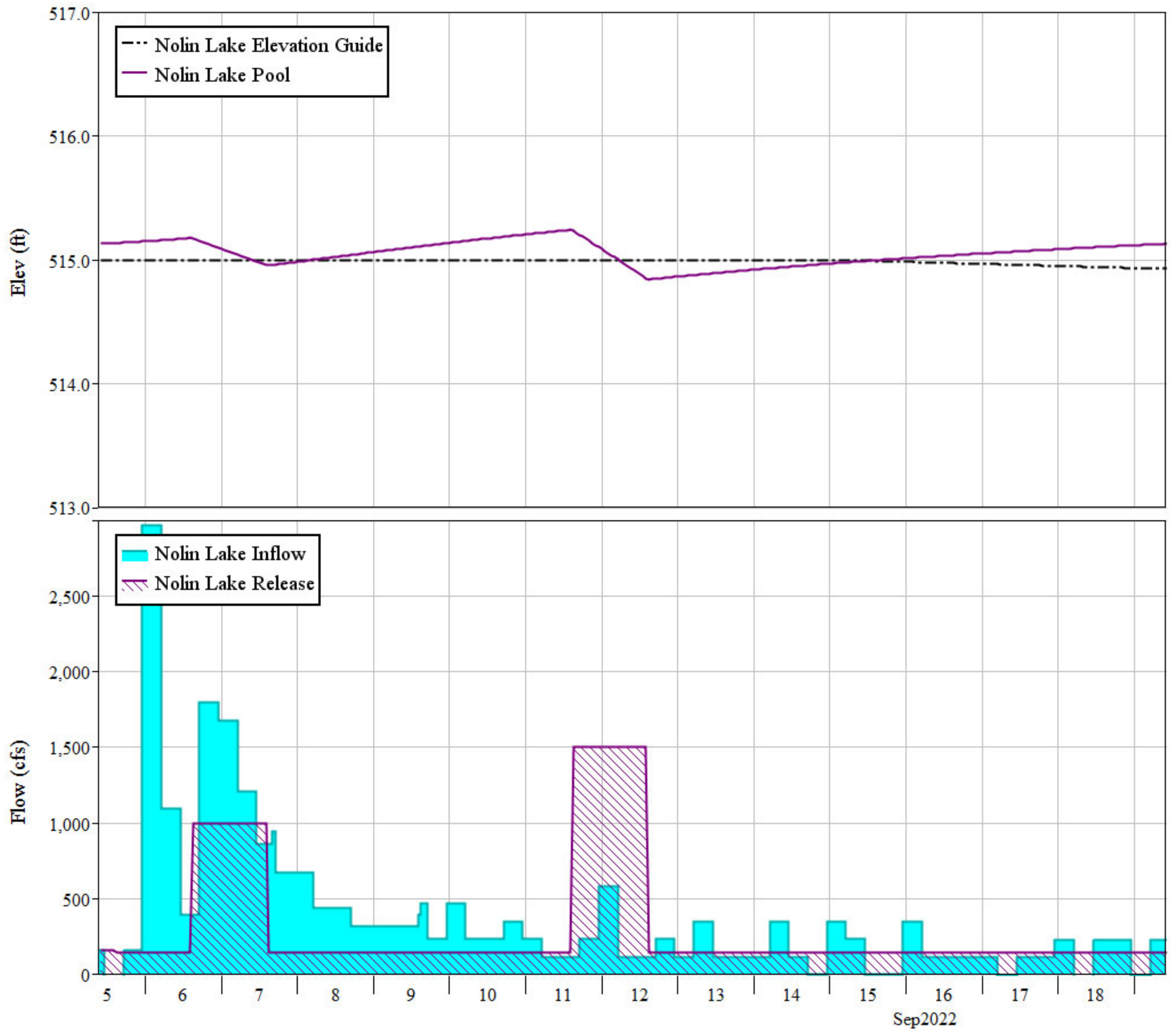

Figure 13. Nolin River Lake, September 2022 – 24-hour pulses (e-flows example).

This is just one way to apply e-flow strategies to Nolin River Lake Dam releases. Dam Operators and Water Managers are encouraged to find different release patterns that fulfill e-flow recommendations while still operating within all other authorized purposes.

Delay drawdown

Late summer (August to October) is a critical time for juvenile mussels and other aquatic organisms. Low flows and warm water are important for juvenile mussels that need to settle into streambeds to begin growing after detaching from fish hosts. The critical time for the Green River Basin aquatic ecosystem is from May to November. Long duration cold releases during these months disturb natural conditions. Please provide flow via bypasses for as long as possible before using main gates to complete the drawdown.

A dry year delayed drawdown scenario is shown in Figure 14. The graphic was created with the most current CWMS modeling suite, using the 2024 water year starting conditions and idealized 50 percentile inflows ranging from 137 – 282 cfs. Release amounts and volumes evacuated are based on Nolin River Lake's specific capabilities and constraints. While idealized, this drawdown is possible to achieve.

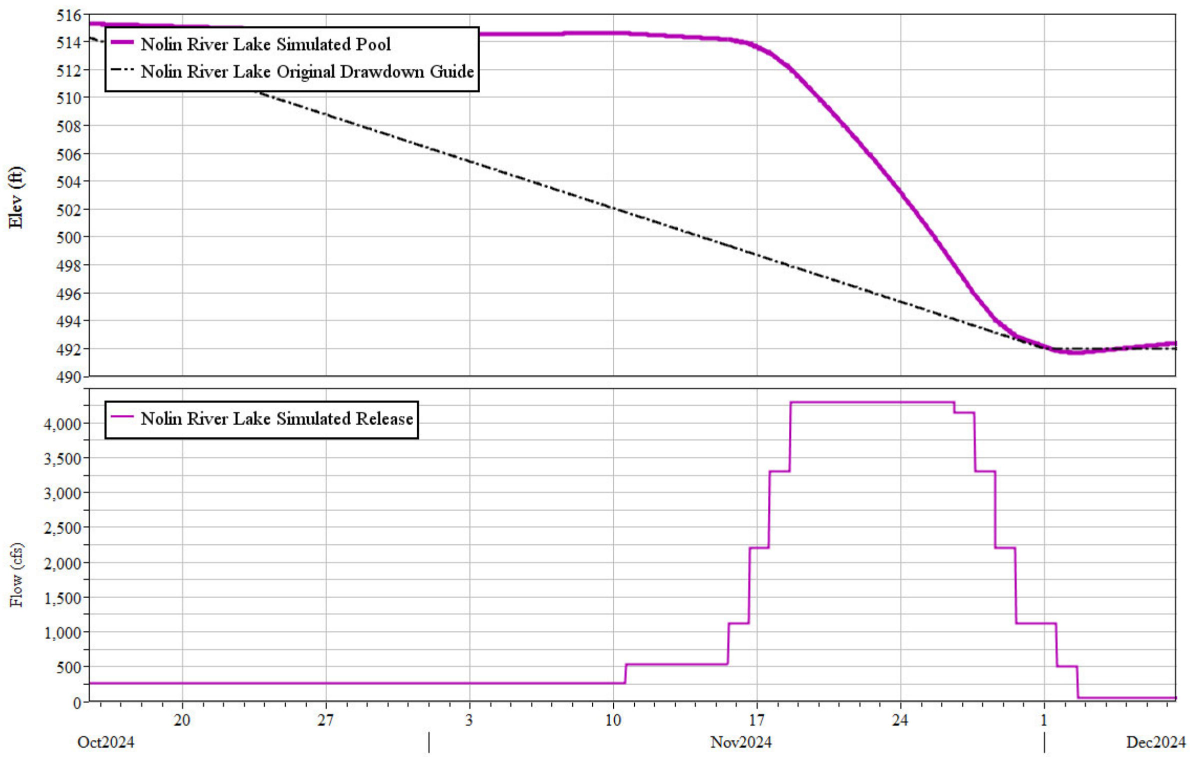

Figure 14. Nolin River Lake, 2024 – Delayed drawdown (e-flows example).

This delayed drawdown scenario may be hard to implement in wet years when flood storage recovery is a priority. Changes in flow regime from year to year is natural, so responding to the current hydrology is appropriate. Delaying the drawdown is the most direct way to simulate natural river conditions on the Nolin and Green rivers within the project authorizations and limitations.

Pre-release using bypasses

The drawdown example above (Figure 14) shows how ~250 cfs can be released during the start of the drawdown period. This lower release is the max capacity of one bypass and allows for multi-level selection (temperature control) while still drawing the pool down slightly. Biologists that work on Nolin River regularly have confirmed that 250 cfs is a "low" flow and will simulate natural conditions adequately. This magnitude of release may not be appropriate on smaller rivers.

Temperature ramp

At the beginning of the drawdown, there should be a multi-day or weeklong transition to cooler temperatures. Main gate releases will drop tailwater temperature significantly and these effects could persist to the confluence of Nolin and Green rivers (depending on natural water conditions) and on downstream. Especially in times of drought or low water, temperature and flow changes should be done as slowly as practical. There is usually a natural temperature drop in the fall that is triggered by air temperatures and shorter days. Continue warmer releases until this natural drop has started if possible. Based on the natural temperature regime, the transition should be limited to a decline of 2°C maximum per day. Large drops in temperature (10°C) should be planned over a week. Consider mixing bypass levels to slow the transition further and mixing bypasses with the main gates for the final transition. Downstream temperatures are influenced by natural runoff and reservoir releases. Natural uncontrolled runoff will be very small at this time in comparison with maximum release from the reservoir. As releases are increased the reservoir releases will start to dominate the volume of the entire river and downstream water temperatures will drop further. Once main gates have been activated and multi-levels can no longer be used, outflows should still be slowly increased due to this temperature/volume dynamic.

Maximum rate of fall

The temperature transition will segue to a flow transition. Humans and aquatic organisms will not be expecting high cold flows in the fall. Transition to high releases should be done over several days or even a week if time allows. It is likely that releasing the maximum amount will cause the pool to fall at a rate greater than 2 ft/day. Instead, 4,000 cfs (or similar) should be targeted to allow the drawdown to be completed in the shortest period.

Flow reduction for bank stability

Nolin River Lake Dam has specific rules for how quickly gates/flow can be increased and decreased. For e-flows it is recommended to change the gates/flow even slower when reducing outflow. Drawing out the receding limb of the release hydrograph has two main benefits: it is the best simulation of a natural flood and it will reduce potential bank sloughing. Recent hydrographs of natural events (inflows) can be used as a template for the reduction but, to release the full volume necessary, it may be advantageous to reduce flow at an even slower rate. The example shown above (Figure 14) accounts for volumetric differences between target summer and winter pools. In wetter years more volume may need to be released.

Swift water rescue training schedule

Nolin River Lake has supported multiple swift water rescue trainings in the tailwaters during past fall drawdowns. This support can continue during a delayed drawdown, however the ideal schedule for these events would be to coincide directly with the delayed releases. Because trainings require high flows with cold water – even a day of training will create damaging conditions in early fall. About 2 weeks of high releases are needed to complete the drawdown. If the drawdown can be delayed until mid-November there will still be flexibility to vary flows to support the trainings. The delay should be assessed with Water Management in September and the scheduled dates for high flows can then be communicated to training coordinators.

Variations due to current conditions (Nolin River Lake)

Figure 15 shows the actual drawdown from 2024, the year preceding the e-flows recommendations. This graph has been included as an acknowledgement that every water year will be different; therefore, each drawdown will be different. In 2024, for instance, the drawdown was delayed in early to mid-October in an attempt to provide flows for a swift water rescue training downstream of the lake in late October. In mid-November, a large inflow event caused releases to be increased to catch up with the guide curve. A good drawdown plan will have contingencies and provide flexibility for current conditions as they arise.

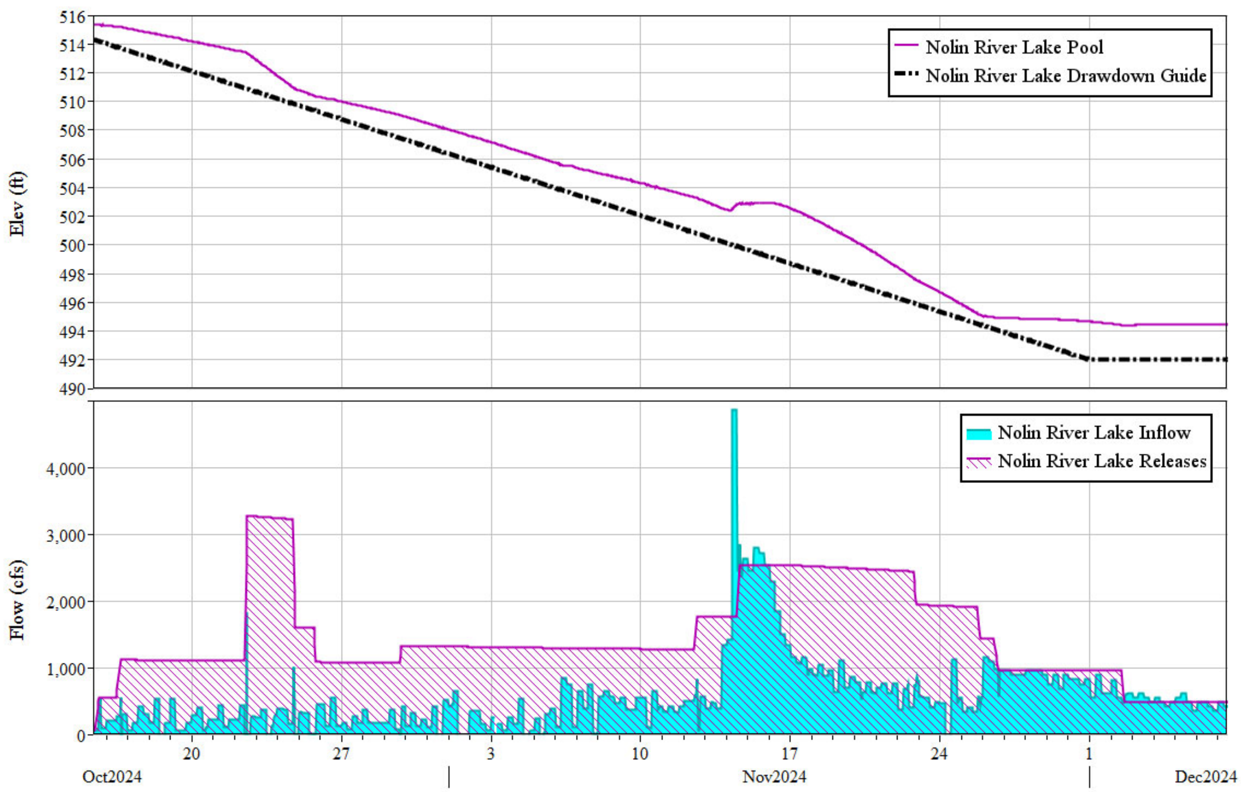

Figure 15. Nolin River Lake drawdown, 2024.

E-flow Guides: Rough River Lake

E-flow release considerations and strategies (Rough River Lake)

The following guidance is most applicable during summer months when stratification of the reservoir causes water quality differences between release levels. The spring filling period is an ideal time to release pulses to trigger spawning and delaying the fall drawdown is the best way to provide warm low releases to encourage juvenile mussel growth. All normal WCM guidance is still applicable (min/max release rules). Flood mitigation, recreation, and other authorized purposes should be balanced as well.

Low flows (temperature regulation)

The highest priority months for low flows are May-November. During these months it is best for the reservoir releases to match inflows to benefit the aquatic environment downstream. Minimum flow requirements from the WCM must still be followed but consider releasing more than the minimum if conditions allow. Always use the current inflow as a guide for the outflow when possible. Apart from low flows being natural in the summer, release of warmer water via the bypass outlets should be a high priority. Native organisms are adapted to warm water temperatures during this time of year and need these conditions to survive.

Pool impacts

The following recreation impacts occur at elevation 500 ft: Axtel camp sites 78-80 flood and water begins to cross the road in the B loop, Laurel Branch sites 47 and 49 flood and the beach parking lot starts to go underwater, and North Fork beach could potentially have to close. In general, try to avoid impacts over the weekend. There are many houses and private docks on the lake. Water levels are tracked closely by the public.

High flows

Releases that require the use of the main gates may have a significant impact on the temperature and chemistry of the riverine habitat downstream. When downstream water levels allow, release water as quickly as possible. The goal should be to return to bypasses as soon as practical. Consider using the previous 24-hr inflow values calculated as the target flow for the release. If a high release (>2,000 cfs) needs to be held longer than two days, then additional consideration should be given to reducing the flow slowly after the peak release. The slow reduction approximates natural events more closely and will help prevent bank sloughing in the downstream channel.

Tailwater impacts

The impacts of large releases on tailwater recreation are minimal at Rough River Lake. The sidewalks, parking lot, and other access points are still accessible during large releases. There is no boat ramp in the tailwater. Downstream access is limited on Rough River, there is a navigation challenge at Falls of Rough, and very few boaters are known to use the river.

Example E-flows (Rough River Lake)

The following examples use historical inflow data from recent years. Starting pool elevations are observed and inflows have been calculated from the observed elevation change of the lake. These simulated scenarios do not include the downstream conditions (like elevated control points or inspections). The purpose of these examples is to better explain the flow recommendations from the SRP stakeholders and help Operators and Water Managers identify events that are ideal for e-flow strategies. While these examples do not directly call out other considerations, all reservoir authorizations must still be followed when releasing an e-flow.

Nolin River Lake, March 2023 – Spawning pulse during fill

In late March 2023, there was a small rain event at Nolin River Lake. Instead of storing all the inflow and filling early, this simulation shows how a pulse release can provide a spawning signal for downstream fish while still following the fill target.

To reduce the amount of gate changes in a single day, 3,000 cfs is initially released, followed by 5,200 cfs. The volume of this simulated release is less than the total inflow so, after the pulse, the reservoir is still 5 ft higher than before the start of the event. Figure 16 highlights the recommendation to evacuate storage as quickly as possible and provide high flow pulses in the spring to trigger fish spawning.

This example at Nolin is included in the Rough River Lake section because it illustrates how e-flow spawning pulses could be provided in spring, which is relevant for both reservoirs.

Rough River Lake, July 2024 – Delayed large pulse

The following event took place in July at Rough River Lake. Sometimes flooding on the Rough and Green rivers can extend into the summer months. This example assumes that the rivers downstream are below flood levels.

At the start of the simulation, Rough River Lake is at a simulated low release providing warm water to the river downstream even though the reservoir is ~1 ft above summer pool. Holding slightly higher than summer pool may allow releases to stay on bypasses, consider the impacts and utilize small amounts of storage when appropriate. A small rain event occurs on July 17th, causing the pool to rise an additional ~1 ft. After the rain event, a simulated pulse release starts at 1,500 cfs for a day, followed by 2,700 cfs for another day. The total volume released in the pulse is more than the volume from the inflow on July17th, which allows the reservoir to take advantage of the cold release on the main gates and return to summer pool quickly. After the pulse, 200 cfs is released to provide warmer temperatures downstream.

Figure 17 illustrates the recommendation to maintain seasonally appropriate warm low flows in the summer, by holding slightly above summer pool. When the main gates are eventually activated for the pulse release - all storage is evacuated as quickly as possible so that lower and warmer outflows through the bypasses can be resumed.

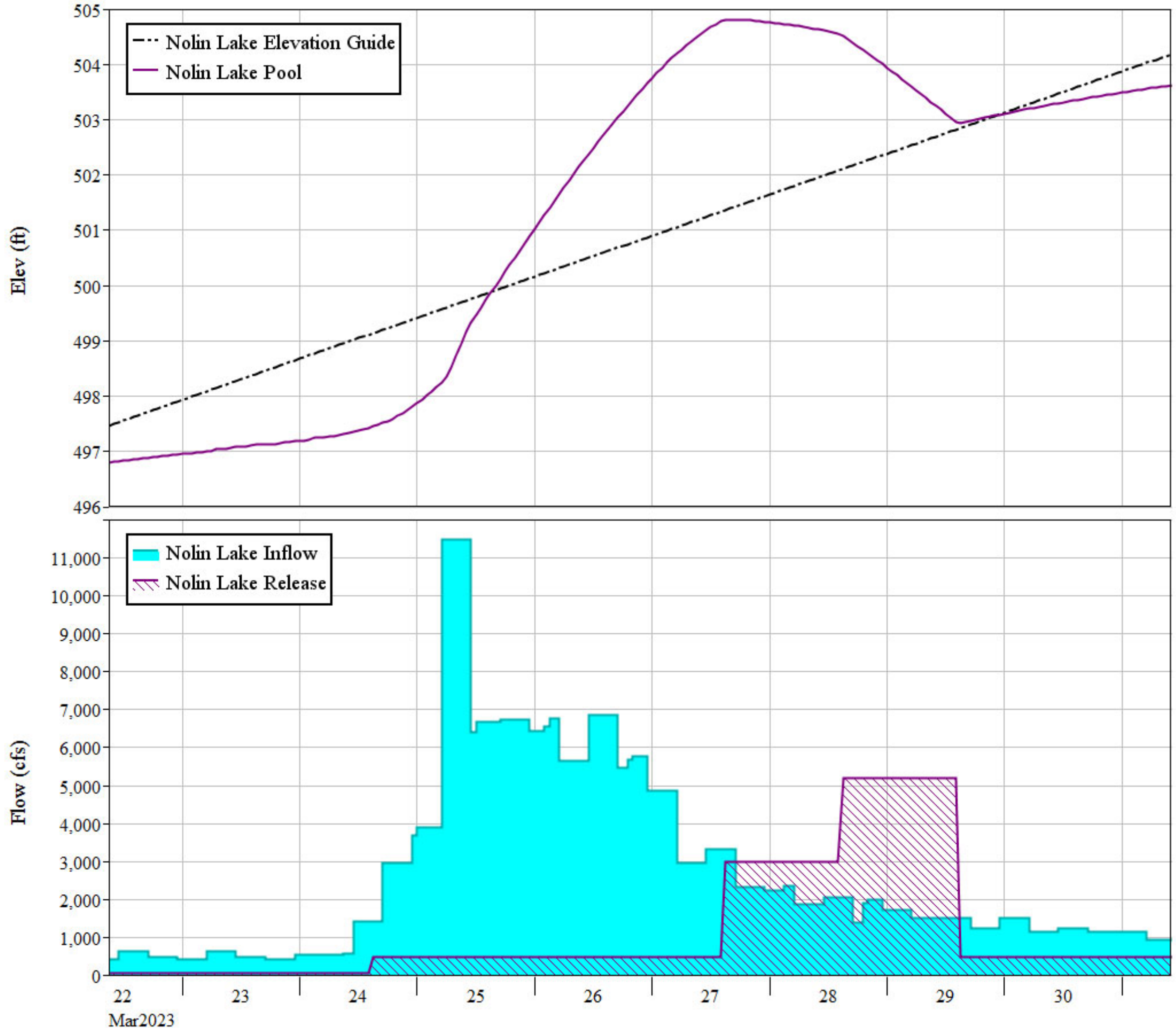

Figure 16. Nolin River Lake, March 2023 – Spawning pulse during fill (e-flows example).

Rough River Lake, June/July 2023 – Multiple pulses

The following events took place in late June and early July at Rough River Lake. Sometimes flooding on the Rough and Green rivers can extend into summer months. This example assumes that the rivers downstream are below flood levels.

At the start of the simulation, Rough River Lake is at a low release providing warm water to the river downstream. The pool rises 0.5 ft because releases are lower than inflows. A simulated medium pulse of 1,000 cfs is started on June 28th and the flow is increased to 1,500 cfs the following day. The pool falls slightly below the guide curve and releases are reduced to 200 cfs, simulating a warm low flow (approximately the max bypass capacity).

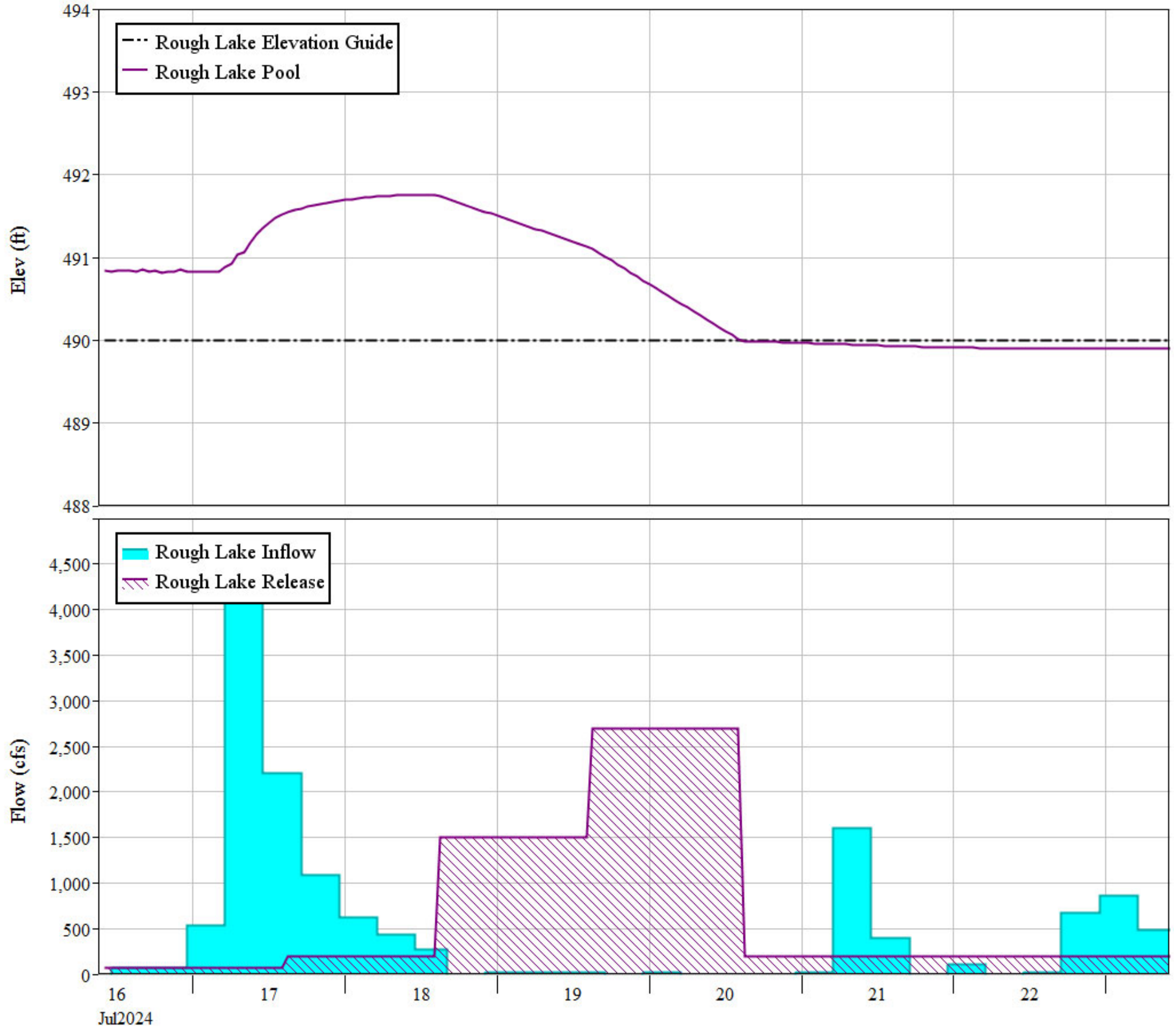

Figure 17. Rough River Lake, July 2024 – Delayed large pulse (e-flows example).

A large inflow event occurs in early July, with a peak inflow of ~9,000 cfs on July 2nd. After the event, a second larger pulse is released from the reservoir. The simulated pulse starts with a release of 1,500 cfs for a day, followed by three days of 2,700 cfs, and ends with 1,500 cfs for a single day. After the pulse, 200 cfs is again released to provide warmer temperatures downstream. If releases had been started one or two days earlier, the pool would not have reached the same elevation. Lower pool elevations are better for the aquatic ecosystem and dam safety Consider releasing during small events if downstream flooding is not a concern. Figure 18 highlights the recommendation to maintain seasonally appropriate warm low flows in the summer while evacuating storage as quickly as possible.

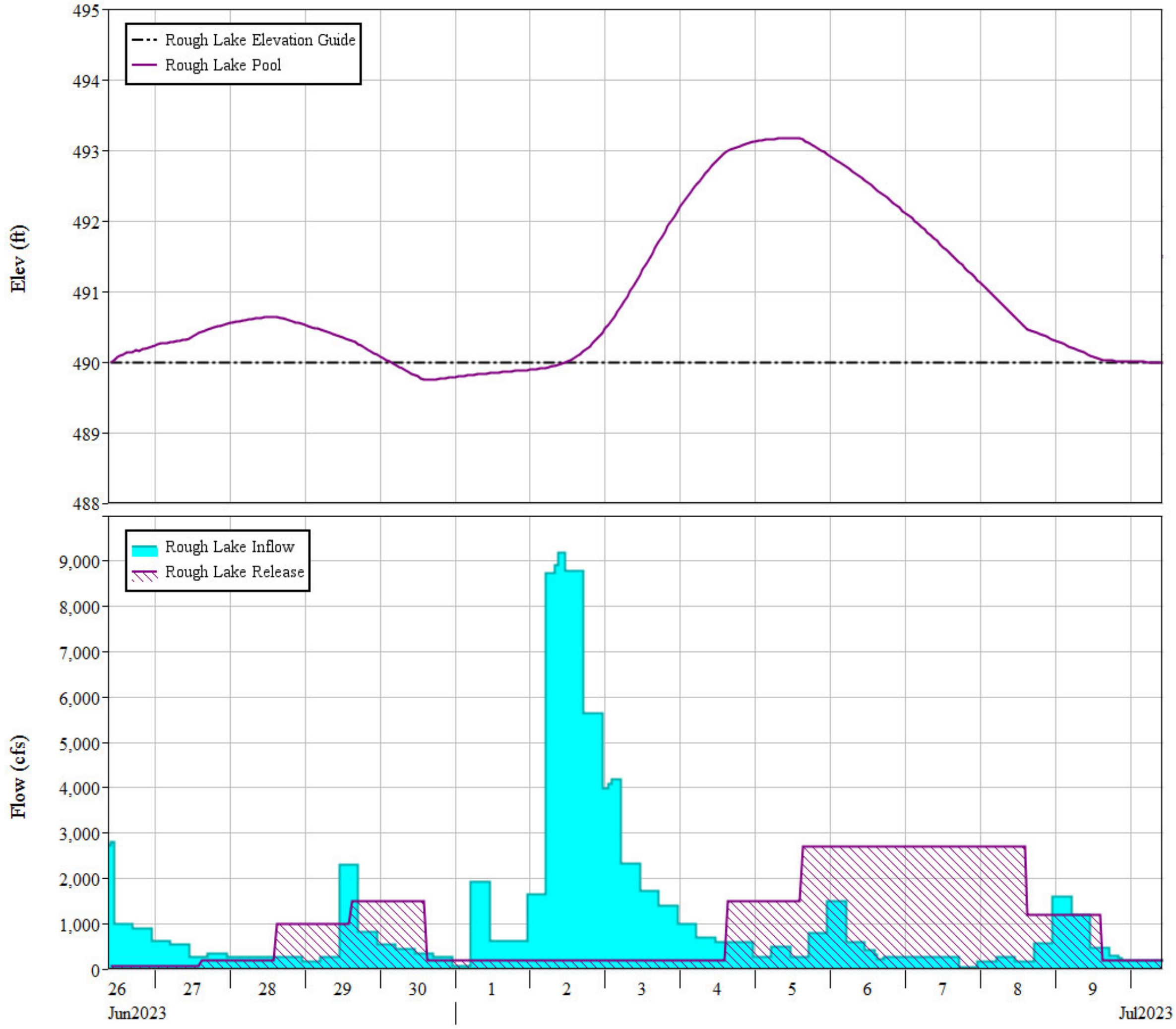

Figure 18. Rough River Lake, June/July 2023 – Multiple pulses (e-flows example).

Rough River Lake, September 2022 – Hold low flows

The following events took place in early September at Rough River Lake. The recommended way to manage these inflows for e-flows would be to hold a low release and use bypasses. While the reservoir is slightly above summer pool, fall is a critical time for juvenile mussel growth. Releases through the main gates would have a negative impact on their ability to survive the coming winter. Consider holding low warm releases if the slightly elevated pool level is not having negative impacts. Figure 19 illustrates the recommendation to maintain seasonally appropriate warm low flows in the fall.

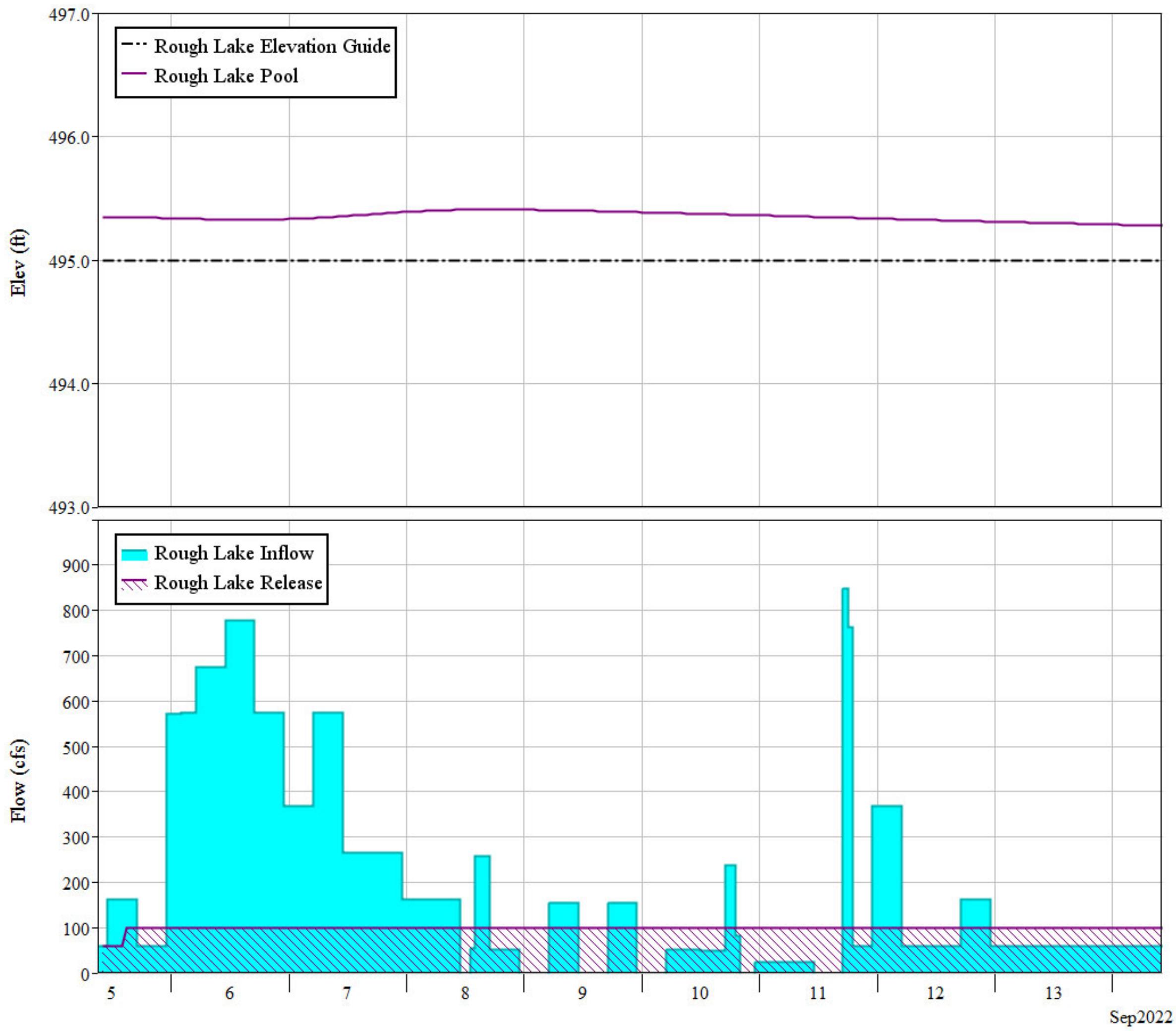

Figure 19. Rough River Lake, September 2022 – Hold low flows (e-flows example).

Delay drawdown

Late summer (August to October) is a critical time for juvenile mussels and other aquatic organisms. Low flows and warm water are important for juvenile mussels that need to settle into streambeds to begin growing after detaching from fish hosts. The critical time for the Rough River Basin aquatic ecosystem is from May to November. Long duration cold releases during these months will disturb natural conditions. Please provide flow via bypasses for as long as possible before using main gates to complete the drawdown.

A dry year delayed drawdown scenario is shown in Figure 20. The graphic was created with the most current CWMS modeling suite, using the 2024 water year starting conditions and idealized 50 percentile inflows ranging from 22 – 82 cfs. Release amounts and volumes evacuated are based on Rough River Lake's specific capabilities and constraints. While idealized, this drawdown is possible to achieve.

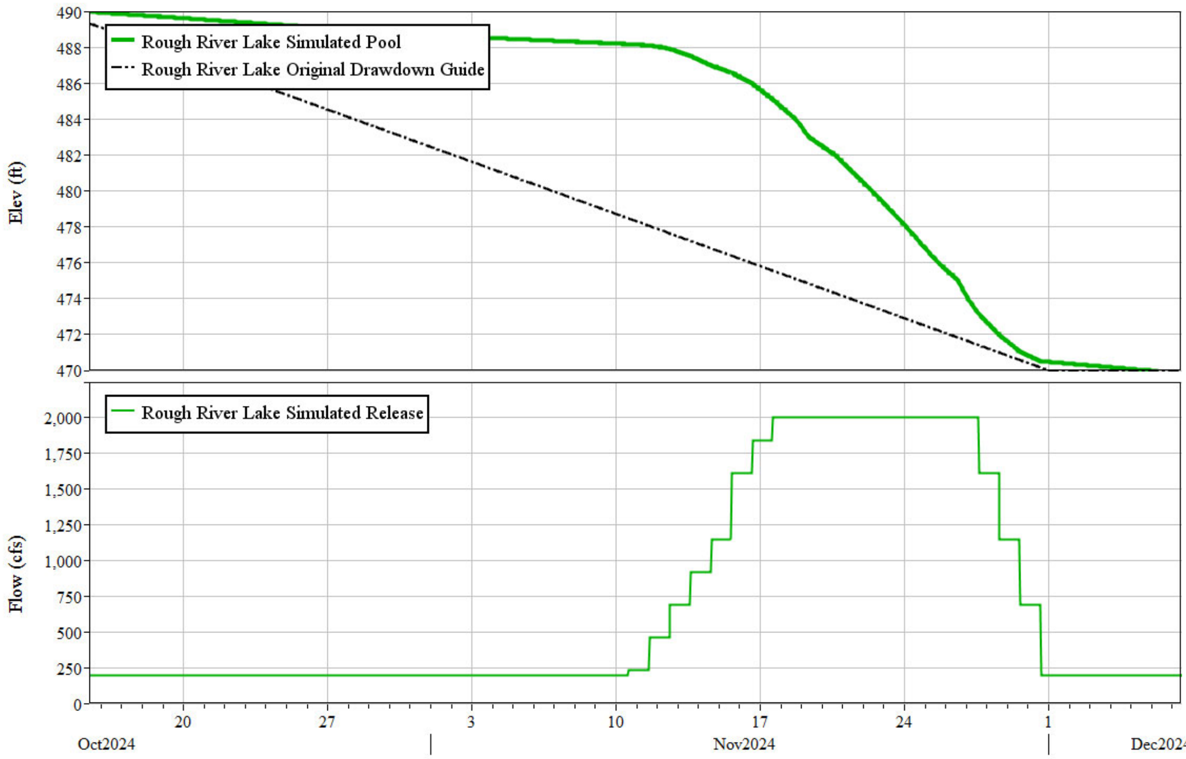

Figure 20. Rough River Lake, 2024 – Delayed drawdown (e-flows example).

This delayed drawdown scenario may be hard to implement in wet years when flood storage recovery is a priority. Changes in flow regime from year to year is natural, so responding to the current hydrology is appropriate. Delaying the drawdown is the most direct way to simulate natural river conditions in the Rough River Basin within the project authorizations and limitations.

Pre-release using bypasses

The drawdown example above (Figure 20) shows how ~200 cfs can be released during the start of the drawdown period. This lower release is the max capacity of both bypasses and allows for a warmer temperature release while still drawing the pool down slightly. Biologists have confirmed that 200 cfs is a "low" flow and will simulate natural conditions adequately. This magnitude of release may not be appropriate on smaller rivers.

Temperature ramp

At the beginning of the drawdown, there should be a multi-day or weeklong transition to cooler temperatures. Main gate releases will drop tailwater temperature significantly. Especially in times of drought or low water, temperature and flow changes should be done as slowly as practical. There is usually a natural temperature drop in the fall that is triggered by air temperatures and shorter days. Continue warmer releases until this natural drop has started if possible. Consider mixing bypasses with the main gates to slow the transition. Downstream temperatures are influenced by natural runoff and reservoir releases. Natural uncontrolled runoff will be very small at this time in comparison with the maximum release from the reservoir. As releases are increased the reservoir releases will start to dominate the volume of the entire river and downstream temperatures will drop further. Once main gates have been activated, outflows should still be slowly increased due to this temperature/volume dynamic.

Maximum stage at Dundee

Humans and aquatic organisms will not be expecting high cold flows in the fall. Transition to high releases should take several days or even a week if time allows. It is likely that releasing the maximum amount will cause the stage at Dundee to exceed 15 ft (crop season limitation). Instead, 2,000 cfs (or similar) should be targeted to allow the drawdown to be completed in the shortest period.

Flow reduction for bank stability

Rough River Lake Dam has specific rules for how quickly gates/flow can be increased and decreased. For e-flows it is recommended to change the gates/flow even slower when reducing outflow. Drawing out the receding limb of the release hydrograph has two main benefits: it is the best simulation of a natural flood and it will reduce potential bank sloughing. Recent hydrographs of natural events (inflows) can be used as a template for the reduction, but to release the full volume necessary, it may be advantageous to reduce flow at an even slower rate. The example shown above (Figure 20) accounts for volumetric differences between summer and winter pool. In wetter years more volume may need to be released.

Variations due to current conditions (Rough River Lake)

Figure 21 shows the actual drawdown from 2024, the year preceding the e-flows recommendations. This graph has been included as an acknowledgement that every water year will be different; therefore, each drawdown will be different. In 2024, for instance, a large inflow event in mid-November caused planned releases to be reduced for downstream mitigation and then increased to resume the drawdown. A good drawdown plan will have contingencies and provide flexibility for current conditions as they arise.

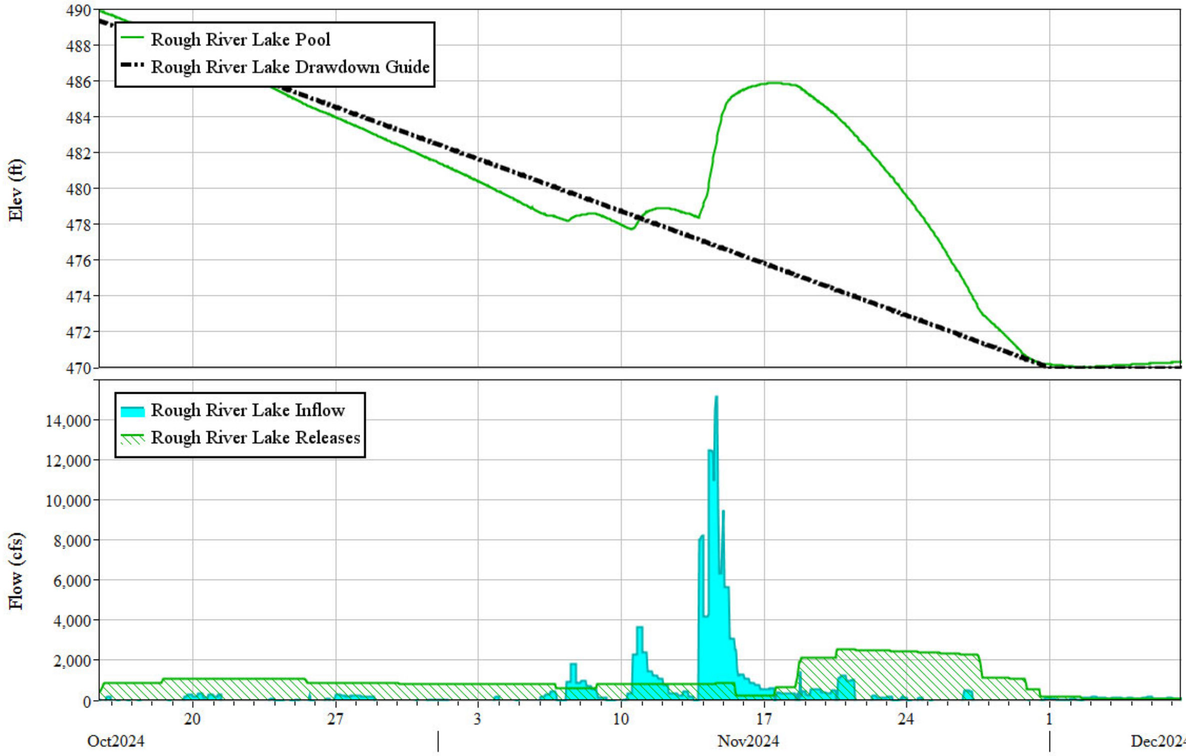

Figure 21. Rough River Lake drawdown, 2024.